Agrociencia

THE MEANING OF 'SUSTAINABILITY' IN DAIRY CATTLE FARMING. A REVIEW OF THE CONCEPT

Enrique **Vázquez-Selem**[1,2,*], Armando **Contreras-Hernández**[1],
Miguel **Equihua-Zamora**[1], Carolina **Álvarez-Peredo**[1]

[1]Red Ambiente y Sustentabilidad. Instituto de Ecología A.C. Carretera Antigua a Coatepec No. 351, Col. El Haya, Xalapa, Veracruz, Mexico. C.P. 91073.
[2]Facultad de Medicina Veterinaria y Zootecnia. Universidad Veracruzana. Miguel Ángel de Quevedo s/n Esq. Yáñez, Veracruz, Veracruz, México. C. P. 91710.
* Author for correspondence: enrvazquez@uv.mx

Citation: Vázquez-Selem E, Contreras-Hernández A, Equihua-Zamora M, Álvarez-Peredo C. 2025. The meaning of `sustainability in dairy cattle farming´. A review of the concept.
Agrociencia. https://doi.org/ 10.47163/agrociencia.v59i2.3294

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: September 04, 2024.
Approved: January 21, 2025.
Published in Agrociencia: February 17, 2025.

ABSTRACT

It is clear that the long-term viability and existence of the planet's life support systems are seriously threatened by environmental degradation. To address this reality, it is necessary to quantify the impacts of human activities that cause this degradation, particularly food production systems. Assessing these impacts in terms of sustainability is therefore essential to quantify their contribution to the overall problem and to design and implement effective policies, corrective measures and compensation mechanisms. Among these systems, dairy cattle production is one of the most questioned due to its high environmental impacts. The concept of sustainability is very broad and in order to address it, this study aims to examine the different existing narratives for its conceptualization, applied to the dairy sector in particular. To this end, a systematic literature review was carried out, which led to the identification of 56 studies whose common objective was to assess the sustainability of cow's milk production. The analysis of this literature, carried out using the SALSA protocol, shows the coexistence of several approaches to defining sustainability, considering simultaneously the three dimensions that make it up: environmental, social and economic. The aim of this study is to identify and typify these different ways of approaching the concept of sustainability, as a useful contribution to the subsequent design of standardized frameworks, methodologies and tools, congruent with the diverse contexts in which dairy farming is developing in the areas of origin of the studies reviewed.

Keywords: sustainability, assessment, dimensions, indicators, concept.

INTRODUCTION

The concept of planetary boundaries was first introduced to define the safe operating space for humanity within the Earth's systems (Rockström *et al.,* 2009). Agricultural production has an impact on several planetary boundaries, as it involves significant use of land, water, and energy resources and generates greenhouse gas emissions. Dairy production intersects significantly with the concepts of planetary boundaries and sustainability, the latter being a recurrent term in the agricultural sector today. Among the many edges of this topic, its evaluation is one of the most diffuse. The first notable difficulty is to find a definition that leaves no room for ambiguity. The concept of "sustainable development" formally appeared on the scene in 1987, as a fundamental contribution of the report Our Common Future, also known as the "Brundtland Report" (WCED, 1987). This document had the merit of recognizing the interrelationship between the environment, society and economy. Although it represented a global effort in the face of multiple warnings of an impending environmental crisis, economic growth still remains as the main driver of wellbeing in current policies.

It should be noted that the term "sustainable development" encompasses two distinct concepts: development and sustainability, each of which can be understood in different ways, depending on the perspective from which it is viewed. These points were taken into account by the Food and Agriculture Organization of the United Nations (FAO) as early as 1991, when a definition of "sustainable agriculture" was formally established: it must be environmentally non-degrading, technically appropriate, economically viable and socially acceptable (FAO, 1991). This definition includes two fundamental aspects: on the one hand, a long-term view ("present and future generations"), and on the other, the importance of the three dimensions or perspectives that must be addressed to create adequate conditions for sustainability: environmental, social and economic. In order to achieve a system that is sustainable across generations, these three dimensions must reach a minimum level (or threshold) of sustainability (Elkington, 1998). However, the conceptual and operational definition of these dimensions remains an open topic of discussion. The boundaries between them, as expressed by the indicators used in the assessment, do not seem to be precise, and it is necessary to establish criteria to define them and create common bases for their evaluation.

Ensuring the viability of the planet's life-support systems is an issue that cannot be postponed (Rockstrom *et al.*, 2023). However, the production models prevailing in most of the world economy are impeding this goal and leading to the depletion of this unique legacy of natural capital (Costanza *et al.*, 2014; Nadal, 2011) and it is not surprising that the interactions between its environmental, social and economic spheres constitute a continuous source of conflicts. Turning the above around implies a shift from previous approaches to sustainability: primary production must cease to be considered as a mere economic activity, and instead be contemplated in its interrelationship with the environmental and social perspectives of productive systems (Rockström *et al*., 2009). A serious analysis of its viability must include these three dimensions. Thus, studies in the agricultural field have evolved from focusing almost exclusively on issues such as economic evaluation, technological intensification and productivity increase, to research from a holistic perspective. The concept of sustainability comprises multiple, often conflicting objectives that are not clearly defined in terms of measurable variables, due to the complexity of the interactions that occur between social, economic and ecological dimensions and their consequent lack of understanding. That which is valuable from an economic perspective frequently impacts adversely on the environmental and social (Chopin *et al*, 2021). The connection between ecological stress and social conflict is widely documented (Rockström *et al.*, 2009; WCED, 1987). Causal relationships can be found in both directions: a conflict can appear as the origin of environmental degradation and this in turn can generate social differences (Steinfeld *et al.*, 2006). Humanitarian conflicts such as those that have occurred in recent times in Haiti, Somalia, Sudan, Rwanda, Ukraine and Palestine, characterized by ethnic differences, overpopulation or famine, also represent calls for attention to environmental problems accumulated over time (Costanza *et al.*, 2014).

The greatest challenge facing food production today is its sustainability, threatened by the availability of natural resources, the pressures on them (Foley *et al.*, 2005, Rockström *et al.*, 2023) and the resulting social and economic problems. Rectifying this course requires the ability to assess the sustainability of agricultural activity. To this end, several initiatives have been developed over the last few decades to quantify the sustainability of agriculture in general, and of its different sectors in particular. Within the primary sector, livestock farming is one of the most questioned activities because of its environmental impact (Steinfeld *et al.*, 2006), which makes its evaluation a priority matter. However, this task is complicated by the heterogeneity of the livestock sector and the vastness of its distribution around the planet. The practice of assessing sustainability requires in the first instance that the term be defined in operational terms, which is usually done by disaggregating the concept into its different fundamental dimensions, which in turn are broken down into themes or components that derive in measurable objectives (Chopin *et al.*, 2021). There exists a variety of methods focused on partial sustainability assessments, in which the environmental and economic perspectives predominate (Arvidsson *et al*., 2020). However, for the integral assessment of sustainability, the range of options is more limited. The aim of this paper is to distinguish and contrast the sustainability concepts which support these latter methods, based on a review of the existing literature. In the discussion section, emphasis is placed on the current ambiguity in the definition of the different dimensions of sustainability, a matter that has a significant impact on their design and also affects the choice of the specific indicators with which each of them is evaluated. Another relevant aspect, also elaborated in the discussion, is the contextuality of these methods, which is strongly associated with their origin, the researcher's interests and the objectives to which they obey. Assessing the sustainability of dairy production systems would greatly benefit from a clear definition of the boundaries and scope of its three dimensions. This would be a step forward in defining research priorities in this area and, consequently, in developing more appropriate assessment methodologies. It should be noted that the scope of this paper is limited to the analysis of sustainability concepts and to some observations on the selection of sustainability indicators, as found in the collection of articles reviewed. The further review of the different methodologies and their indicators is not included here due to space limitations and will be presented in a future publication.

MATERIALS AND METHODS

The typological category *systematized review*, selected according to the classification established by Grant and Booth (2009), was used to conduct the bibliographical search and further analysis of the material. It is characterized as a solid and reproducible method for the search, categorization, and synthesis of published knowledge on a particular topic. The results elucidate current advances in the subject and contrast with other retrospective approaches, as well as opening the possibility of exploring new perspectives on the subject and highlighting the existing gaps in the knowledge of the subject. The search, appraisal, synthesis and analysis of relevant literature were carried out according to the SALSA protocol (Search, AppraisaL, Synthesis, Analysis), which allows the scope of the review to be narrowed according to the objective being considered (Grant and Booth, 2009). This process consists of the following phases:

1. Search: a search for contributions to the topic in databases
2. Appraisal: the application of criteria defined for the inclusion/exclusion of studies.
3. Synthesis: of narrative and tabular types.
4. Analysis: presenting a synthesis of the current state of the knowledge and areas of opportunity for future research.

The search was delimited by two objectives:

a) To identify literature that deals with methodologies to evaluate sustainability in cattle milk production, considering its three dimensions: environmental, social, and economic.
b) Once identified the relevant literature, the next requirement was that it should also include an empirical validation of the proposed methodology.

The search was performed in the databases Web of Science and ScienceDirect for English-language publications, and in Redalyc and SciELO for open access publications in Ibero-American journals, Google Scholar for general English-language publications, and Google Académico for general Spanish-language publications. For each of these, search terms were defined according to the characteristics of the particular search engine; i.e., Web of Science allows high levels of specificity in the identification of documents, in contrast to the search engine of Google, which yields very generic results and a high number of irrelevant documents. The relatively small number of results obtained from Google Scholar was due to the decision to restrict the keyword search exclusively to article titles. If this adjustment were not made, the number of results returned by the search engine would be unmanageable for the purposes of this study. The search in Google Scholar enabled the capture of some additional references that did not appear in the other databases.

The search terms used were chosen to match the search engine of each database or source consulted. The period considered for all databases was January 2000 to August 2024 (Table 1).

Table 1. Search terms used in the identification of scientific publications related to the evaluation of dairy production sustainability in its three dimensions: environmental, social, and economic.

Database	Search terms
Web of Science	Dairy OR cattle livestock (Title) AND sustainab* OR integral* (Topic) AND environment* AND soci* AND econom* (Topic) AND assessment OR valuation OR index OR indicator OR appraisal OR estimat* (Topic) NOT buffalo OR goat OR sheep OR camel (Topic)
Science Direct	Title: dairy OR cattle OR cow OR milk Title, abstract, keywords: (social OR socioeconomic) AND (economical OR economic) AND (environment OR environmental) AND (sustainable OR sustainability)
Redalyc	(Evaluación OR cuantificación OR indicadores) AND (sustentabilidad) AND (“producción lechera” OR lechería OR leche) AND (ambiental AND ecológica AND económica AND social) NOT (oveja OR cabra OR caprino)
SciELO	ti:(“producción lechera” OR lechería OR leche) AND (ab:(sustentabilidad OR sustentable)) AND (ab:(evaluación OR cuantificación OR medición OR indi*))
Google Scholar	intitle:(dairy OR milk OR cattle) AND intitle:(sustainable OR sustainability) AND intitle:(assessment OR appraisal OR index) AND intext: (“three pillars” OR “triple bottom line”) AND intext:(environmental AND social AND economic) -buffalo -goat -sheep -industry -transport -transportation
Google Académico	allintitle:(evaluación OR indicadores) + (sustentabilidad OR sostenibilidad) + (leche OR lechera OR lechería) -cabra -oveja -bufalo -transporte

Geographic restrictions were not considered, since the aim was to determine the progress made both in developed countries, where most of the literature originates, and in developing countries, particularly those of Latin America. For this last reason, in addition to articles written in English, the review also included documents published in Spanish and Portuguese. During the course of the individual article reading and revision, snowballing was used as an aid to include relevant articles not captured in the search but referenced within the body of literature. Each article under review was filtered through the inclusion and exclusion criteria (Table 2).

Table 2. Criteria of inclusion and exclusion of literature.

Category	Criterion
Inclusion	Search terms appear as specified Publication in a peer-reviewed journal Original research on methodologies to assess sustainability in cow's milk production, in its three dimensions Empirical validation of the methodology is included Articles written in English, Spanish, or Portuguese language Articles published between January 2000 and August 2024
Exclusion	Generic evaluation studies, applied to other production systems, not specifically for cow's milk production Methodologies that consider only one or two dimensions

RESULTS AND DISCUSSION

Bibliographic review

The outcome of the systematic search, in terms of the number of articles detected and included from each data base, is detailed in Table 3. Regarding the origin and validation of the studies, 32 come from Europe, 20 from Latin America, where Brazil is prominent with six articles, Mexico with three and the remaining four equally from Africa (Tanzania), North America (Canada), Asia (India), and Oceania (Australia). The relative proportions of each zone are shown in Figure 1. The minimal presence of these latter three regions and its respective countries, which rank among the largest global milk producers, is noteworthy.

Table 3. Database of origin of the articles included in the review phase.

Database	Articles detected	Articles included
Web of Science	227	29
Science Direct	70	12
Redalyc	1,102	7
SciELO	1	0
Google Scholar	512	5
Google Académico	101	1
Other references (snowballing)	5	2
Total	**2,017**	**56**

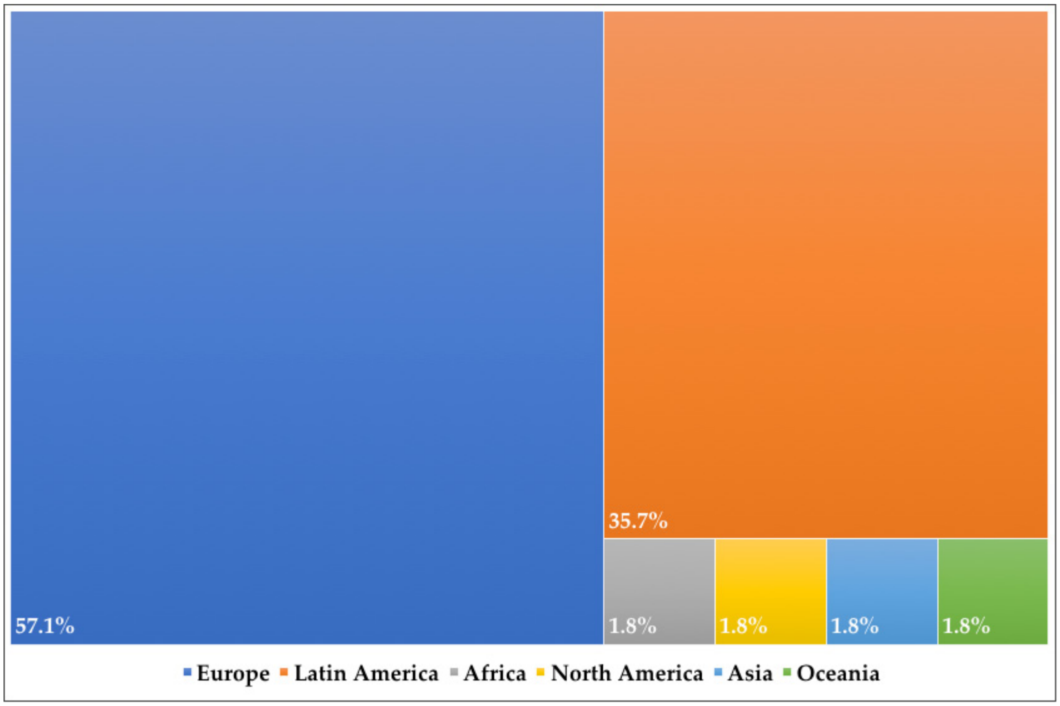

Figure 1. Origin of the articles included in the review.

Sustainability conceptions and indicators selection

The variety of indicators used to evaluate each dimension of sustainability reflect the wide gamut of sustainability conceptions applicable for each dimension, as viewed by each author. Organizing these contrasts in a comprehensible manner was the next step in the analysis.

The contribution of agriculture to the welfare of society has been, until recent times, usually determined by its economic contribution. However, sustainability studies nowadays tend to integrate economic assessment with environmental performance and the overall welfare of society. This leads one to note the lack of a consensual definition of "sustainability", despite its widespread use and relevance. In the first instance, the assessment of sustainability requires that it be defined in operational terms, creating an association with measurable variables. This results in a complex categorization but allows for a common language that facilitates discussion among stakeholders about the complex relationship between natural and human systems. Bockstaller *et al*. (2009) highlight the diversity of approaches and the lack of a formal methodology to compare them. Therefore, a number of preliminary choices and assumptions need to be made before defining a sustainability framework. These stem from a set of basic questions, as arised by Lélé and Norgaard (1996), regarding the definition of "sustainability": *'What is to be sustained, at what scale, and in what form? Over what time period and with what level of certainty? Through what social process and* *with what tradeoffs against other social goals?'*. Little research has focused on this line, and a tool capable of comprehensively assessing dairy systems in particular, viewing economic, environmental and social sustainability as a complex interactive system, is not yet available. As an example, widely used methodologies such as life cycle analysis (LCA), which could ideally combine the environmental dimension, economic costing, and even the social aspect has not been explored enough (Chen and Holden, 2017; Rivera-Huerta *et al*, 2019). Designing such a tool should at first focus on establishing the necessary definitions of the different dimensions of sustainability, delineating their boundaries and potential assessment methodologies.

This is an open debate: there is a multiplicity of tools for sustainability assessment, covering a broad spectrum of objectives, from the general to the particular. Several methods exist designed for the assessment of agriculture in general, and susceptible of being adapted to different productive sectors through the contextualization of their attributes and indicators: SAFA, Sustainability Assessment of Food and Agriculture (FAO 2014), RISE, Response Inducing Sustainability Evaluation (Häni *et al.*, 2003), IDEA, Indicators of Durability of Agricultural Exploitations (Zahm *et al.*, 2008), MOTIFS, Monitoring Tool for Integrated Farm Sustainability (Meul *et al.*, 2008) and MESMIS, Framework for the Evaluation of Natural Resource Management Systems Incorporating Sustainability Indicators (Astier *et al.*, 2012) are relevant examples of this kind. In addition, 39 different methods specifically designed for the dairy sector were identified. The following table lists the 56 references reviewed, the country or region in which they were validated, and the application for which they were originally designed (Table 4).

Table 4. Papers included in the review, country/region of origin and original application of the methodology.

No.	Reference	Country/ region	Aplication
1	Cruz F, Pardo D, Horcada A, Mena Y. 2024. An Assessment of Sustainability of Dual-Purpose, Dairy and Beef Cattle Production Systems in the Cundinamarca Department (Colombia) Using the MESMIS Framework. Sustainability 16 (16): 7054. https://doi.org/10.3390/su16167054	Colombia	Agriculture (adapted)
2	Fariña S, Vigil Moreno O, Candioti F, Villanueva C, Sanchez Ledezma W, Moscoso C, Cajarville C, Charlón V, Urbina Abaunza L, Guacapiña Viteri A *et al.* 2024. Milk production systems in Latin America and the Caribbean: Biophysical, socio-economic, and environmental performance. Agricultural Systems 218: 103987. https://doi.org/10.1016/j.agsy.2024.103987	Latin America	Dairy

Table 4. Continue.

3	Oyinbo O, Hansson H. 2024. Information provision and preferences for more sustainable dairy farming: Choice experimental evidence from Sweden. Agricultural and Resource Economics Review 53 (1): 119–143. https://doi.org/10.1017/age.2023.33	Sweden	Dairy
4	Pavanello C, Franchini M, Bovolenta S, Marraccini E, Corazzin M. 2024. Sustainability Indicators for Dairy Cattle Farms in European Union Countries: A Systematic Literature Review. Sustainability 16 (10): 4214. https://doi.org/10.3390/su16104214	Europe	Dairy
5	Sánchez-Hidalgo M, Tadich T. 2024. Use of Delphi methodology to select sustainability indicators on dairy farms: an exploration of environmental, economic, social and animal welfare dimensions. Austral Journal of Veterinary Sciences 56 (2): 91–97. https://doi.org/10.4206/ajvs.562.05	Latin America	Dairy
6	Feil AA, do Amaral CC, Schreiber D, Maehler AE. 2023. Sustainability performance of small and medium dairy enterprises in Brazil. Sustainable Production and Consumption 39: 301–310. https://doi.org/10.1016/j.spc.2023.05.024	Brazil	Dairy
7	Lovarelli D, Leso L, Bonfanti M, Porto SMC, Barbari M, Guarino M. 2023. Climate change and socio-economic assessment of PLF in dairy farms: Three case studies. Science of the Total Environment 882: 163639. http://dx.doi.org/10.1016/j.scitotenv.2023.163639	Italy	Dairy
8	Robling H, Hatab AA, Säll S, Hansson H. 2023. Measuring sustainability at farm level –A critical view on data and indicators. Environmental and Sustainability Indicators 18: 100258. https://doi.org/10.1016/j.indic.2023.100258	Sweden	Dairy
9	Torres Jara de García GP, Durand-Chávez LM, Quispe-Ccasa HA, Linares-Rivera JL, Segura Portocarrero GT, Calderón TR, Vásquez Pérez HV, Maicelo Quintana JL, Ampuero Trigoso G, Robles Rodríguez RR *et al.* 2023. Sustainability of livestock farms: The case of the district of Moyobamba, Peru. Heliyon 9 (2): e13153. https://doi.org/10.1016/j.heliyon.2023.e13153	Peru	Dairy
10	Wilfart A, Baillet V, Balaine L, Díaz de Otálora X, Dragoni F, Krol DJ, Fratczak-Müller J, Rychla A, Rodriguez DGP, Breen J *et al.* 2023. DEXi-Dairy: an ex-post multicriteria tool to assess the sustainability of dairy production systems in various European regions. Agronomy for Sustainable Development 43 (6): 82. https://doi.org/10.1007/s13593-023-00935-3	Europe	Dairy
11	Zhu L, Schneider K, Lansink AO. 2023. Economic, environmental, and social inefficiency assessment of Dutch dairy farms based on the dynamic by-production model. European Journal of Operational Research 311 (3): 1134–1145. https://doi.org/10.1016/j.ejor.2023.05.032	Nederlands	Dairy

Table 4. Continue.

12	Zira S, Röös E, Rydhmer L, Hoffmann R. 2023. Sustainability assessment of economic, environmental and social impacts, feed-food competition and economic robustness of dairy and beef farming systems in South Western Europe. Sustainable Production and Consumption 36: 439–448. https://doi.org/10.1016/j.spc.2023.01.022	Europe	Dairy
13	Jiménez C, Marín K, Jácome E, López V, Larrea R. 2022. Indicadores para la evaluación de sustentabilidad de pequeños productores de leche de la provincia de Cotopaxi. Revista Recursos Naturales Producción y Sostenibilidad 1 (1): 50–60. http://190.15.139.149/index.php/RENPYS/article/download/487/584	Ecuador	Agriculture (adapted)
14	Iseppi L, Rosa F, Bassi I. 2022. A Multi-Criteria Decision approach for the sustainable dairy farm management. Quality-Access to Success 23 (191). 242–252. https://dx.doi.org/10.47750/QAS/23.191.29	Italy	Dairy
15	Zhu L, Lansink AO. 2022. Dynamic sustainable productivity growth of Dutch dairy farming. PLoS ONE 17 (2): e0264410. https://doi.org/10.1371/journal.pone.0264410	Nederlands	Dairy
16	Da Silva MF, Castro Moreira MV, Gameiro AH. 2021. Relationship between cost and sustainability indicators in milk farms. Custos e Agronegocio Online 17 (4): 358–388. http://www.custoseagronegocioonline.com.br/numero4v17/OK%2017%20sustentabilidade%20english.pdf	Brazil	Dairy
17	Díaz de Otálora X, Del Prado A, Dragoni F, Estellés F, Amon B. 2021. Evaluating three-pillar sustainability modelling approaches for dairy cattle production systems. Sustainability 13 (11): 6332. https://doi.org/10.3390/su13116332	Europe	Dairy
18	Torres-Lemus E, Martínez-García CG, Prospero-Bernal F, Arriaga-Jordán CM. 2021. On-farm assessment of the sustainability of small-scale dairy systems with three methods based on indicators. Tropical Animal Health and Production 53 (208): 1–17. https://doi.org/10.1007/s11250-021-02658-7	Mexico	Agriculture (adapted)
19	Novaira B, Gimenez G, Marini PR. 2021. Sustentabilidad asociada al traspaso generacional en un tambo. FAVE Sección Ciencias Veterinarias 20 (1): 50–58. https://doi.org/10.14409/favecv.v20i1.9768	Argentina	Dairy
20	Roesch A, Nyfeler-Brunner A, Gaillard G. 2021. Sustainability assessment of farms using SALCAsustain methodology. Sustainable Production and Consumption 27: 1392–1405. https://doi.org/10.1016/j.spc.2021.02.022	Switzerland	Agriculture (adapted)
21	Balaine L, Dillon EJ, Läpple D, Lynch J. 2020. Can technology help achieve sustainable intensification? Evidence from milk recording on Irish dairy farms. Land Use Policy 92: 104437. https://doi.org/10.1016/j.landusepol.2019.104437	Ireland	Dairy

Table 4. Continue.

22	Bánkuti FI, Prizon RC, Damasceno JC, De Brito MM, Pozza MSS, Lima PGL. 2020. Farmers' actions toward sustainability: A typology of dairy farms according to sustainability indicators. Animal 14 (S2): s417–s423. https://doi.org/10.1017/S1751731120000750	Brazil	Dairy
23	Rios GP, Botero S. 2020. An Integrated Indicator to Analyze Sustainability in Specialized Dairy Farms in Antioquia–Colombia. Sustainability 12 (22), 9595. http://dx.doi.org/10.3390/su12229595	Colombia	Dairy
24	Zanin A, Dal Magro CB, Kleinibing Bugalho D, Morlin F, Afonso P, Sztando A. 2020. Driving sustainability in dairy farming from a TBL perspective: Insights from a case study in the West Region of Santa Catarina, Brazil. Sustainability 12 (15): 6038. https://doi.org/10.3390/su12156038	Brazil	Dairy
25	Munyaneza C, Kurwijila LR, Mdoe NS, Baltenweck I, Twine EE. 2019. Identification of appropriate indicators for assessing sustainability of small-holder milk production systems in Tanzania. Sustainable Production and Consumption 19: 141–160. https://doi.org/10.1016/j.spc.2019.03.009	Tanzania	Dairy
26	Chen W, Holden NM. 2018. Tiered life cycle sustainability assessment applied to a grazing dairy farm. Journal of Cleaner Production 172: 1169–1179. https://doi.org/10.1016/j.jclepro.2017.10.264	Ireland	Dairy
27	Godoi MG, Bánkuti FI, Moreira M, Prizon RC, Kuwahara KC, Soares dos Santos M, Damasceno JC. 2018. Development and application of a sustainability assessment model for dairy production systems. Semina: Ciências Agrárias 39(6): 2685–2702. https://doi.10.5433/1679-0359.2018v39n6p2685	Brazil	Dairy
28	Kocjančič T, Debeljak M, Žgajnar J, Juvančič L. 2018. Incorporation of emergy into multiple-criteria decision analysis for sustainable and resilient structure of dairy farms in Slovenia. Agricultural Systems 164: 71–83. https://doi.org/10.1016/j.agsy.2018.03.005	Slovenia	Agriculture (adapted)
29	Micha E, Heanue K, Hyland JJ, Hennessy T, Dillon EJ, Buckley C. 2017. Sustainability levels in Irish dairy farming: a farm typology according to sustainable performance indicators. Studies in Agricultural Economics 119 (2): 62–69. http://dx.doi.org/10.7896/j.1706	Ireland	Dairy
30	Neves AP, Ríos-Osorio LA, Cassarino JP, Mayer PH. 2017. Propuesta metodológica para la caracterización socioecológica de unidades familiares de producción y vida en el campo. Revista Mexicana de Ciencias Agrícolas 8 (6): 1409–1426. https://doi.org/10.29312/remexca.v8i6.311	Brazil	Socioecology (adapted)

Table 4. Continue.

31	De Olde EM, Oudshoorn FW, Sørensen CA, Bokkers EA, de Boer IJ. 2016. Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice. Ecological Indicators 66: 391–404. http://dx.doi.org/10.1016/j.ecolind.2016.01.047	Denmark	Agriculture (adapted)
32	Chand P, Sirohi S, Sirohi SK. 2015. Development and application of an integrated sustainability index for small-holder dairy farms in Rajasthan, India. Ecological Indicators 56: 23–30. http://dx.doi.org/10.1016/j.ecolind.2015.03.020	India	Dairy
33	Van Asselt ED, Capuano E, Van der Fels-Klerx, HJ 2015. Sustainability of milk production in the Netherlands –A comparison between raw organic, pasteurized organic and conventional milk. International Dairy Journal 47: 19–26. http://dx.doi.org/10.1016/j.idairyj.2015.02.007	Nederlands	Dairy
34	Vargas JC, Benítez D, Torres V, Ríos S, Soria S. 2015. Factors determining the efficiency of milk production in systems of double purpose in Pastaza province, Ecuador. Cuban Journal of Agricultural Science, 49(1): 17–21. http://scielo.sld.cu/pdf/cjas/v49n1/cjas03115.pdf	Ecuador	Dairy
35	Salas-Reyes IG, Arriaga-Jordán CM, Rebollar-Rebollar S, García-Martínez A, Albarrán-Portillo B. 2015. Assessment of the sustainability of dual-purpose farms by the IDEA method in the subtropical area of central Mexico. Tropical Animal Health and Production 47 (6): 1187–1194. https://doi.org/10.1007/s11250-015-0846-z	Mexico	Agriculture (adapted)
36	Elsaesser M, Jilg T, Herrmann K, Boonen J, Debruyne L, Laidlaw AS, Aarts F. 2014. Quantifying sustainability of dairy farms with the DAIRYMAN sustainability-index. Grassland Science in Europe 20: 367–376. https://www.europeangrassland.org/fileadmin/documents/Infos/Printed_Matter/Proceedings/EGF2015.pdf#page=386	Germany	Dairy
37	Buys L, Mengersen K, Johnson S, Van Buuren N, Chauvin A. 2014. Creating a *Sustainability Scorecard* as a predictive tool for measuring the complex social, economic and environmental impacts of industries, a case study: Assessing the viability and sustainability of the dairy industry. Journal of Environmental Management 133: 184–192. http://dx.doi.org/10.1016/j.jenvman.2013.12.013	Australia	Industry (adapted)
38	Dolman MA, Sonneveld MPW, Mollenhorst H, de Boer IJM. 2014. Benchmarking the economic, environmental and societal performance of Dutch dairy farms aiming at internal recycling of nutrients. Journal of Cleaner Production 73: 245–252. http://dx.doi.org/10.1016/j.jclepro.2014.02.043	Nederlands	Dairy
39	Jaklič T, Juvančič L, Kavčič S, Debeljak M. 2014. Complementarity of socio-economic and emergy evaluation of agricultural production systems: The case of Slovenian dairy sector. Ecological Economics 107: 469–481. http://dx.doi.org/10.1016/j.ecolecon.2014.09.024	Slovenia	Agriculture (adapted)

Table 4. Continue.

40	Rodríguez I, Torres V, Martínez O, Orta LD. 2014. Evaluación técnica, socioeconómica y medioambiental de una empresa genética de Mayabeque, Cuba, mediante el modelo estadístico de medición de impacto (MEMI). Revista Cubana de Ciencia Agrícola 48 (3): 219–226. https://www.redalyc.org/articulo.oa?id=193032133003	Cuba	Dairy
41	Acosta-Alba I, Lopéz-Ridaura S, van der Werf HM, Leterme P, Corson MS. 2012. Exploring sustainable farming scenarios at a regional scale: an application to dairy farms in Brittany. Journal of Cleaner Production 28: 160–167. http://dx.doi.org/10.1016/j.jclepro.2011.11.061	France	Dairy
42	Binder CR, Schmid A, Steinberger JK. 2012. Sustainability solution space of the Swiss milk value added chain. Ecological Economics 83: 210–220. https://doi.org/10.1016/j.ecolecon.2012.06.022	Switzerland	Industry (adapted)
43	Meul M, Van Passel S, Fremaut D, Haesaert G. 2012. Higher sustainability performance of intensive grazing versus zero-grazing dairy systems. Agronomy for Sustainable Development 32: 629–638. https://doi.org/10.1007/s13593-011-0074-5	Belgium	Agriculture (adapted)
44	Oudshoorn FW, Kristensen T, Van Der Zijpp AJ, de Boer IJM. 2012. Sustainability evaluation of automatic and conventional milking systems on organic dairy farms in Denmark. NJAS-Wageningen Journal of Life Sciences 59 (1–2): 25–33. https://doi.org/10.1016/j.njas.2011.05.003	Denmark	Dairy
45	Arias-Reverón J, Calvo C, Chaves N, Granados MDM, Hernández JR, Uribe-Lorío L, WingChing-Jones R. 2012. Uso de indicadores para determinar la sostenibilidad de tres proyectos productivos de universidades en Costa Rica. UNED Research Journal 4 (2): 203–212. https://doi.org/10.22458/urj.v4i2.9	Costa Rica	Dairy
46	Bélanger V, Vanasse A, Parent D, Allard G, Pellerin D. 2012. Development of agri-environmental indicators to assess dairy farm sustainability in Quebec, Eastern Canada. Ecological Indicators 23: 421–430. https://doi.org/10.1016/j.ecolind.2012.04.027	Canada	Dairy
47	Tommasino H, García Ferreira R, Marzaroli R, Gutiérrez R. 2012. Indicadores de sustentabilidad para la producción lechera familiar en Uruguay: análisis de tres casos. Agrociencia Uruguay 16 (1): 166–176. https://doi.org/10.31285/agro.16.583	Uruguay	Dairy
48	Kuosmanen T, Kuosmanen N. 2009. Role of benchmark technology in sustainable value analysis. An application to Finnish dairy farms. Agricultural and Food Science 18: 302–316. https://doi.org/10.23986/afsci.5953	Finland	Industry (adapted)

Table 4. Continue.

49	Vayssières J, Guerrin F, Paillat JM, Lecomte P. 2009. GAMEDE: A global activity model for evaluating the sustainability of dairy enterprises Part I–Whole-farm dynamic model. Agricultural Systems 101 (3): 128–138. https://doi.org/10.1016/j.agsy.2009.05.001	France	Dairy
50	Vayssières J, Bocquier F, Lecomte P. 2009. GAMEDE: A global activity model for evaluating the sustainability of dairy enterprises. Part II – Interactive simulation of various management strategies with diverse stakeholders. Agricultural Systems 101(3): 139–151. https://doi.org/10.1016/j.agsy.2009.05.006	France	Dairy
51	Del Prado A, Scholefield D. 2008. Use of SIMSDAIRY modelling framework system to compare the scope on the sustainability of a dairy farm of animal and plant genetic-based improvements with management-based changes. The Journal of Agricultural Science 146 (2): 195–211. https://doi.org/10.1017/S0021859608007727	United Kingdom	Dairy
52	Meul M, Van Passel S, Nevens S, Dessein J, Rogge E, Mulier A, Van Hauwermeiren A. 2008. MOTIFS: a monitoring tool for integrated farm sustainability. Agronomy for Sustainable Development 28 (2): 321–332. https://doi.org/10.1051/agro:2008001	Belgium	Agriculture (adapted)
53	Parra-López C, Groot JCJ, Carmona-Torres C, Rossing WAH. 2008. Integrating public demands into model-based design for multifunctional agriculture: An application to intensive Dutch dairy landscapes. Ecological Economics 67 (4): 538–551. http://dx.doi.org/10.1016/j.ecolecon.2008.01.007	Nederlands	Agriculture (adapted)
54	Van Calker KJ, Berentsen PBM, Giesen GWJ, Huirne RBM. 2008. Maximising sustainability of Dutch dairy farming systems for different stakeholders: A modelling approach. Ecological Economics 65 (2): 407–419. https://doi.org/10.1016/j.ecolecon.2007.07.010	Nederlands	Dairy
55	Kirner L, Kratochvil R. 2006. The role of farm size in the sustainability of dairy farming in Austria: An empirical approach based on farm accounting data. Journal of Sustainable Agriculture 28 (4): 105–124. https://doi.org/10.1300/J064v28n04_09	Austria	Dairy
56	Hernández Valenzuela D, Herrera Haro JG, Pérez Pérez J, Vázquez Agustín S. 2006. Índice de sustentabilidad para el sistema bovino de doble propósito, en Guerrero, México. REDVET. Revista Electrónica de Veterinaria 7 (9): 1–11. https://www.redalyc.org/articulo.oa?id=63612675002	Mexico	Agriculture (adapted)

At this point, it is worth highlighting the relevance of tools adapted and contextualized to local needs. As interest in sustainability assessment began to rise, most proposed methodologies approached evaluation as a linear process —a straightforward, step-by-step progression that assumes a direct relationship between actions and outcomes. However, these methodologies often lacked a solid foundation for deriving meaningful and appropriate indicators, limiting their ability to address the complex and interconnected nature of sustainability. Emphasis was placed in the obtention of a final rating among the technological and management options, instead of exploring a change in management practices or venturing in joint analysis which might include the local producers (Astier *et al., 2008)*. Top-bottom designs, in which the tools are developed by people not directly involved in the productive process (academic, technical or political experts), yield very different priorities than those that result when stakeholders are given the opportunity to participate in this design process. In this case, there is a risk that the priorities of the stakeholders may lead to a bias in the design of the methodology, as the perception of the farmers, who may not be aware of the environmental impact issues, may differ from the environmental aspects considered as precise indicators of sustainability. Or, conversely, when actors not closely related to the farm and its context make decisions about processes with which they are unfamiliar. Munyaneza *et al.* (2019), comparing the indicators resulting from top-bottom and bottom-up design processes, for the specific case of Tanzania, reports that *'in the list of environmental indicators, some were noticeable by their absence. Indicators considered relevant in other studies, such as greenhouse gas emissions and manure use were rejected by the respondents as not relevant in this study context. This could be explained by the subsistence nature of the studied milk production systems, where economic indicators are more relevant to stakeholders than environmental indicators.'* The plain quotation is relevant, since such is the case in poor or underdeveloped countries, where producers are primarily concerned with survival over any other priority. In this regard, it's worth mentioning successful experiences where the involvement of small farmers in rural areas has been essential to achieving successful results in developing alternatives for natural resource management. (Astier *et al.*, 2012; García-Barrios and González-Espinosa, 2017)

De Olde *et al.* (2017) adds to this debate, by delineating a framework to assess the choices involved in the development of a sustainability assessment tool and question their implications in such development, as well as the influence of personal context, values, assumptions and understandings. In the absence of a general agreement in this regard, the debate on the definition of *sustainability* remains open, leading to the coexistence of a wide variety of positions on the subject. Most of authors who reflect on the issue of sustainability acknowledge the fact that the concept is broad and requires a broad consensus as well. Paradoxically, the next common step in this process is for each author to add his or her own preferred definitions, which in turn contributes to the lack of consensus (Bell and Morse, 2008) and the iteration of this loop. In order to clarify some basic points, the following subsections elaborate on the discussion of the three dimensions of sustainability.

Environmental sustainability

In its original form, sustainability was closely associated to maintaining environmental quality (Bell and Morse, 2008), however since the introduction of the definition by the WCED (1987) the concept widened to include economic and social welfare as well. Environmental sustainability is largely associated with two different mainstreams: environmental impacts and ecosystem services. Livestock farming has a high degree of responsibility in the environmental impact of human activities and is the cause of a large part of the world's greenhouse gas emissions (Steinfeld *et al.,* 2006; Arvidsson *et al.,* 2020; De Olde *et al.,* 2016). Measurement of this type of impact, as well as others like acidification and eutrophication, is usually performed with Life Cycle Assessment (LCA) methodologies, the normal standard worldwide for this type of evaluation.

Application of LCA methods is particularly well suited to account for interactions among livestock systems, the environment, and on-farm management decisions, through integrated modelling approaches, more or less complex, depending on the scope of the analysis. On the other hand, biophysical tools are not best suited for adequately capturing social and economic sustainability issues, because they employ different valuation perspectives (Gasparatos and Scolobig, 2012). The assessment of the environmental dimension entails another type of difficulty, due to the diversity of production systems on the planet, their heterogeneity, and the difficulty involved in their quantification (Chopin *et al.,* 2021). Under current methodologies, environmental attributes such as biodiversity are still far from reaching the level of importance that they deserve as a global priority. Only a handful of the articles reviewed considered take biodiversity into account as a theme or indicator, and mostly in a shallow manner. The same undervaluation also applies to ecosystem services, which are essential to life and thus key indicators for an adequate representation of sustainability.

A broader criteria approach is crucial for developing an appropriate policy framework towards sustainable agriculture. Several authors point out that the actions at farm level are negligible, so to achieve significant improvements towards long-term sustainability the mainstream economic system needs to be redesigned (Costanza *et al.*, 2014; Nadal, 2011). Keeping yields high enough to sustain economic benefits often delivers results not in line with environmental targets. Consequently, questions raise regarding whether sustainable farming should be rewarded as an ecosystem service or whether the environmental targets defined today are feasible for the dairy sector. An analysis of global livestock production systems shows that in the future, within the context of a carbon-constrained economy and strong competition for natural resources, particularly land and water, livestock intensity might be severely affected. For instance, the demand for animal foods may be diminished by environmental and socioeconomic factors, such as concerns about human health, green production systems, and changes in socio-cultural values. Societal values and goals also make a difference, which largely depend on local contexts. For instance, in some developed economies, food production may not be a major social issue since self-sufficiency guarantees the national supply. But in contrast, keeping the viability of rural regions, a goal closely linked to sustainable agriculture and forestry, is a hot social topic and thus appears reflected in agricultural policy measures (Mann and Gazzarin, 2004).

Social sustainability

Although the integration of the social dimension into the definition of sustainability has progressed, the proliferation of social sustainability concepts has led to a problem on which most authors agree: there is no homogeneity in this matter (Janker *et al.*, 2019). Criticism of the previous neglect of the social dimension in the concept of sustainability has led to increased attention to this aspect. However, this progress is not yet sufficient to develop a consistent understanding of what the social dimension actually means. Littig and Griessler (2005) put it in these words: *'social sustainability appears to be more a catchword of politicians than a well-developed concept'.*

The need for a common understanding of the social dimension of sustainability in agriculture is evolving into a new paradigm for social sustainability: sustainable development must be socially inclusive, equitable and participatory, with equity for marginalized segments. These concerns should be taken into account when considering the long-term sustainability of agricultural systems, but their practical boundaries are currently a matter of contextual definition: they shift according to the origin of the study and the interests of the researcher. Although there may be conceptual agreement, the operationalization of social sustainability assessment differs, and it is possible to observe two clearly defined lines: a) developed countries (mainly Europe) and b) developing countries (Latin America, Africa and Asia).

Social acceptance of a production system implies that it must be integrated into its social-cultural context, be respectful of people and animals, and contribute to equitable management of resources. This social pillar is related to the search for a more equitable distribution of profit, in a manner that favors social inclusion, a dignified life, and generalized access to resources and social services, to improve rights and reduce the differences between the living standards of the population, particularly in minorities and discriminated sectors.

While the debate continues, the assessment of social sustainability is currently based on indicators such as social welfare, employment, marginalization, income distribution, social "bads" (work-related illness, accidents, safety), and even animal welfare and milk quality, both of which are considered social demands and therefore included by several authors as indicators of social sustainability. A common problem in underdeveloped areas of the world is the low educational level of farmers. It constitutes a barrier to driving changes and evaluating productive systems. In such cases, economic urgency obscures the underlying social problem and prevails in the eyes of farmers as the main dimension of sustainability (Munyaneza *et al*., 2019).

In developed countries, the assessment of social sustainability is also strongly associated with labor conditions (de Olde *et al.*, 2016). In certain contexts, the assessment of social sustainability allows the addressing of potential problems related to insufficient income that can lead to the financial dependence of farmers on economic schemes as state subsidies, which may represent an important source of income for primary producers. In such countries, labor efficiency is a relevant indicator of social sustainability. The social contribution of the production system is signified by the labor indicator, which corresponds to the amount of employment in farms. However, employment is an ambiguous category: it can be assigned to both the social and economic dimensions of sustainability.

In contrast, in many developing countries, dairy production units are mostly managed by family labor, in many cases with predominantly female labor, as in India (Chand *et al.,* 2015). For Mann and Gazzarin (2004), when family interests predominate in a dairy enterprise, the owners' revenue turns into a social indicator, since maintaining a sufficient income is one of the main conditions allowing farms to continue to operate and thereby fulfill a social function: that of supplying dairy products to urban consumers.

The profit or income from family labor is therefore considered a social attribute. This indicator, in per capita terms, can be related to average consumption in rural areas: the higher the per capita income in relation to consumption, the greater the social sustainability of the enterprise. Gender equality has become an important attribute of the social dimension of sustainability since, in some areas, women work equally in the family dairy enterprise. Another important indicator of social sustainability in developing countries is the harshness of the work, i.e., the conditions under which it is carried out, particularly in the case of physical labor (Chand *et al.,* 2015).

It is important to emphasize that, under this perspective, family production units are more than a profitable enterprise: they are a livelihood, both social and ecological, for families in the agrarian space. For this reason, there are other processes –besides the productive process– that must be integrated into the conception of family production units as socioecological systems, such as the collective reflection on sustainability problems, the socioecological description of complex agricultural systems, and understanding their socio-ecological resilience in order to collaborate in decisions towards sustainability (Neves *et al.,* 2017). In general terms, this social dimension is related to the continued satisfaction of basic human needs such as food, shelter and socialization, as well as the right to culture, security, justice, freedom, education, employment and recreation.

Economic sustainability

The depletion of essential resources is a clear sign that the global economic system, as it is currently configured, is causing serious damage to the planetary ecosystems (Nadal, 2011; Costanza *et al.*, 2014). From a theoretical perspective, economic sustainability can be considered in two ways: The first focuses on the sustainable use of natural resources, which implies that economic sustainability is achieved when economic activity is not conducted at the expense of natural resource depletion This concept corresponds to the principle of "strong" sustainability (Giddings *et al.,* 2002). The second focuses on the growth of the economic system in terms of gross domestic product, which implies the substitutability of the different forms of capital. This latter principle corresponds to the concept of “weak” sustainability, originally derived from the WCED report (WCED, 1987).

In order to assess the economic performance of production units, the common practice in all of the studies reviewed is to resort to the use of financial-accounting indicators, which focus on providing monetary information, since the survival of the productive system itself depends on its financial viability (Arvidsson *et al.,* 2020). Such indicators of financial performance and technological efficiency of the farms are the most commonly used, although some studies have integrated not mainstream socioeconomic concepts such as *Sustainable Value* (Kousmanen and Kuosmanen, 2009) and *Net Social Benefit* (Parra-López *et al.,* 2007). Both of these concepts focus on the creation of economic value for society as a whole, based on a more or less efficient use of the resources available for productive activity, and are valued in monetary terms. This is practical in the case of marketable goods but has its drawbacks in the valuation of benefits that do not have a clear market value (e.g. habitat quality and biodiversity), which are instead valued using other *ad-hoc* methods.

Indicators selection

Of the three dimensions, the economic appears as the most clearly defined, since it is based on widely used indicators that can be easily expressed in a common quantitative term –monetary– while the social dimension is undoubtedly the one with the most diffuse characterization since the indicators used are less consistent, due to the lack of a common currency, such as monetary in the case of the economic dimension or biophysical in the case of the environmental dimension. In some studies, social indicators are reduced to labor indicators, while others include more variety, such as social welfare, property, food security, education, quality of life, social organization and participation, landscape heritage, and intergenerational transfer. For the attribute of animal welfare, which is a societal demand, some studies oversimplify its assessment to a single biophysical indicator –the somatic cell count in milk.

Within the set of indicators selected to evaluate sustainability, certain cases appear in two or even three dimensions, i.e., they are assigned to one or the other criterion at the author’s discretion. For example, animal welfare, milk quality and dependence on subsidies appear in all three dimensions, although the first two of them only reach a significant level in the social dimension, and subsidies tilt towards the economic dimension. In the case of the environmental dimension, greenhouse gases (GHG) are the most recurrent indicator, followed closely by energy consumption. The low incidence of assessment of ecosystem services as environmental variables is notable. This can be partly explained by the type of papers selected for analysis, as well as the complexity inherent to the assessment.

CONCLUSIONS

The systematized literature search identified 56 articles addressing the topic of sustainability assessment in dairy production from the perspective of its three dimensions. This set of studies provides a useful picture of the state of knowledge on the subject, from which several aspects can be highlighted. First, the fact that a great variety of dairy production systems coexisting on the planet greatly complicates the task of designing a "universal" application method. This leads to the development of field research in various directions, in which the local interest of the researcher is often the determining factor. Measuring sustainability is a task with a high degree of intrinsic complexity, and the variety of possible techniques and approaches to the problem act to further complicate the task.

As a result of this review, it has been possible to identify several priority areas of opportunity for the future in this field. First, there is a notorious lack of homogeneity in the definition of the dimensions of sustainability. It seems clear that this is a contextual problem, i.e. one that may have different solutions depending on the particular conditions of each region or production system. It is also clear that there is no common path or established methodology for selecting indicators. Given the large number of possible indicators, in the range of hundreds, it seems necessary to have a standardized methodology or protocol to identify those that are most appropriate in a given context. As mentioned in the previous paragraph, this is a problem that requires local solutions.

As a consequence of the above points, it is not surprising that a wide range of evaluation methodologies is available. Selecting the most appropriate one in a given context becomes a challenge that requires solutions that have not yet been fully developed. The creation of a methodology adapted to the conditions of family systems in developing countries is a field that deserves to be explored in the future.

Much of the literature reviewed coincides in highlighting the lack of tools and standardized methodologies to carry out an integrated evaluation that measures the potential impacts, both positive and negative (trade-offs), that strategies employed in one dimension can have on the others. One of the major problems to be solved lies precisely in this fact; methodologies for the selection, collection, and analysis of indicators suitable for evaluating dairy farms are still multiple and temporally and spatially specific, making it difficult to establish relationships and connections between the results of one or another study. The catalog of proposals has been increasing, particularly in the last 15 years however, no consensus has been reached in establishing uniform conceptions of sustainability which allow to monitor the state of dairy systems, in a way that adapts to the specific characteristics of each region. As shown in this review, the multiplicity of conceptions suggests that the sustainability assessment of dairy farms is more an emerging field than a neatly defined issue. This is a rather complex issue, which correlates the state of the environment, production factors, technology, scarce resources availability and societal priorities as key drivers.

ACKNOWLEDGEMENTS

This project was supported by the Instituto de Ecología, A.C. and the Universidad Veracruzana, Mexico.

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