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Peer review history for:

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The original manuscript for review is appended below.

Reviewer 1: Round 1
Date completed: 19 March 2025
Recommendation: Accept / **Revisions required** / Resubmit for review / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

Does the manuscript fall within the scope of SAJS?
Yes/No
Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?
Yes/No
Does the manuscript contain sufficient novel and significant information to justify publication?
Yes/No
Do the Title and Abstract clearly and accurately reflect the content of the manuscript?
Yes/No
Is the research problem significant and concisely stated?
Yes/No
Are the methods described comprehensively?
Yes/No
Is the statistical treatment appropriate?
Yes/No/**Not applicable**/Not qualified to judge
Are the interpretations and conclusions justified by the research results?
Yes/Partly/No
Please rate the manuscript on overall contribution to the field
Excellent/**Good**/Average/Below average/Poor
Please rate the manuscript on language, grammar and tone
Excellent/**Good**/Average/Below average/Poor
Is the manuscript succinct and free of repetition and redundancies?
Yes/No
Are the results and discussion confined to relevance to the objective(s)?
Yes/No
The number of tables in the manuscript is
Too few/**Adequate**/Too many/Not applicable

The number of figures in the manuscript is
Too few/**Adequate**/Too many/Not applicable
Is the supplementary material relevant and separated appropriately from the main document?
Yes/No/Not applicable
Please rate the manuscript on overall quality
Excellent/**Good**/Average/Below average/Poor
Is appropriate and adequate reference made to other work in the field?
Yes/No
Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?
Yes/No/**Not applicable**
If accepted, would you recommend that the article receives priority publication?
Yes/**No**
Are you willing to review a revision of this manuscript?
Yes/No
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.
Yes/No

Comments to the Author:

The authors have designed an index with which foods can be evaluated, based on existing information of certain parameters. This is an adaptation of existing and similar indexes that were built on nutritional aspects. The index was limited to milk and plant-based beverages that are used for similar purposes in households as milk. In the current model the impact on environment and economic viability was included. This is innovative and makes the index useful for applications in areas other than only nutrition. As such the work is publishable. The document is well written and does not need linguistic editing. Apart from 3 minor aspects, the document may be published.

There are three aspects that caught my attention:

1. While reading the parameters that were included in the index, I could not help wondering about the bioavailability of nutrients such as certain minerals. However, the authors have explained the reason for the exclusion thereof in line 347. The explanation is sound and valid.
2. In lines 261-263 the authors mentioned that chicken manure was used to fertilise almonds. This practice was then classified under post-harvest grazing, similar to the oats produced for oat milk (line 264). I cannot agree with this; post-harvest grazing of oats means that the oats serve a double purpose: food and fodder. In the case of almonds, they serve a single use as human food. Use of chicken manure makes the chicken serve a double purpose, but not the plant that is fertilsed. The points scored by the chicken cannot be allocated to a crop plant.
3. The title of Table 1 refers to sex (of humans). For humans the correct word is "gender", while "sex" is preferred when referring to animals. Please make sure that this is addressed in the text of the document where applicable.

Author response to Reviewer 1: Round 1

While reading the parameters that were included in the index, I could not help wondering about the bioavailability of nutrients such as certain minerals. However, the authors have explained the reason for the exclusion thereof in line 347. The explanation is sound and valid.
AUTHOR: Thank you. The research is busy progressing, however, not there yet. The advisors and research team decided against it but will continue to investigate the ongoing research.
In lines 261-263 the authors mentioned that chicken manure was used to fertilise almonds. This practice was then classified under post-harvest grazing, similar to the oats produced for oat milk (line 264). I cannot agree with this; post-harvest grazing of oats means that the oats serve a double purpose: food and fodder.

In the case of almonds, they serve a single use as human food. Use of chicken manure makes the chicken serve a double purpose, but not the plant that is fertilised. The points scored by the chicken cannot be allocated to a crop plant.
AUTHOR: Thank you. I fully agree with the statement when considering quantitative measures such as carbon-cycling and life cycle emissions, However, this paragraph specifically refers to qualitative sustainability indicators which point towards management rather than actual nutrient flow. The allocation of chicken manure as “post-harvest grazing” is more for the purposes of gaining points for better soil management and utilising the concept of recycling and repurposing in the farm, as well as the benefits associated with using manure instead of synthetic fertiliser – which is either by muck spreading or post-harvest grazing. The selectable options according to table S10.2.B under livestock use was 1) none, 2) TMR, 3) post-harvest grazing, 4) TMR with fodder carry, 5) Pasture based monocrop, 6) pasture-based mixed. Thus to fairly credit the farmer for the incorporation of livestock into the farming system indirectly, chicken manure was allocated as post-harvest grazing. However, this will be clarified in text and a limitation will be added into the discussion or conclusion to improve the model with more options for the use of livestock on farm and for the handling of manure. Thank you.
The title of Table 1 refers to sex (of humans). For humans the correct word is “gender”, while “sex” is preferred when referring to animals. Please make sure that this is addressed in the text of the document where applicable.
AUTHOR: Thank you, this has been corrected. I appreciate your positive feedback and helpful critique. Thank you for the detail in which you have reviewed this manuscript.

Reviewer 2: Round 1
Date completed: 04 June 2025
Recommendation: Accept / **Revisions required** / Resubmit for review / Resubmit elsewhere / Decline / See comments
Conflicts of interest: None

Does the manuscript fall within the scope of SAJS?
Yes/No
Is the manuscript written in a style suitable for a non-specialist and is it of wider interest than to specialists alone?
Yes/No
Does the manuscript contain sufficient novel and significant information to justify publication?
Yes/No
Do the Title and Abstract clearly and accurately reflect the content of the manuscript?
Yes/No
Is the research problem significant and concisely stated?
Yes/**No**
Are the methods described comprehensively?
Yes/**No**
Is the statistical treatment appropriate?
Yes/No/Not applicable/Not qualified to judge
Are the interpretations and conclusions justified by the research results?
Yes/**Partly**/No
Please rate the manuscript on overall contribution to the field
Excellent/**Good**/Average/Below average/Poor
Please rate the manuscript on language, grammar and tone
Excellent/Good/**Average**/Below average/Poor

Is the manuscript succinct and free of repetition and redundancies?	
Yes/No	
Are the results and discussion confined to relevance to the objective(s)?	
Yes/No	
The number of tables in the manuscript is	
Too few/**Adequate**/Too many/Not applicable	
The number of figures in the manuscript is	
Too few/**Adequate**/Too many/Not applicable	
Is the supplementary material relevant and separated appropriately from the main document?	
Yes/No/Not applicable	
Please rate the manuscript on overall quality	
Excellent/Good/**Average**/Below average/Poor	
Is appropriate and adequate reference made to other work in the field?	
Yes/**No**	
Is it stated that ethical approval was granted by an institutional ethics committee for studies involving human subjects and non-human vertebrates?	
Yes/**No**/Not applicable	
If accepted, would you recommend that the article receives priority publication?	
Yes/**No**	
Are you willing to review a revision of this manuscript?	
Yes/No	
With regard to our policy on 'Publishing peer review reports', do you give us permission to publish your anonymised peer review report alongside the authors' response, as a supplementary file to the published article? Publication is voluntary and only with permission from both yourself and the author.	
Yes/No	

Comments to the Author:

1. Having a detailed list of databases, the number of reviewed papers and the process followed, e.g., a PRISMA diagram, is necessary for the reproducibility of the methodology used.
2. "S7: Percentage of raw material in final product, based on market investigations in Gauteng." This table indicated that an average of 100% bovine milk was used in the finished product. This is a strong claim, and the need for more evidence or support could be provided. This table and other table findings should also be discussed if they align with existing research findings.
3. Due to the nature and high relevance of the paper to existing food systems, there is a need for direct, clear and actionable recommendations to relevant stakeholders. Also, inclusion of direct benefits in the policy should be included.
4. Relevant papers from 2023-2025 should be included, as recent research findings keep being updated in the papers. The papers from 2013 and below should be updated with more recent versions.
5. An addition on the justification of using almond, oat and soy beverages should be added. Also, the justification for bovine milk choices should be given.

Author response to Reviewer 2: Round 1

Having a detailed list of databases, the number of reviewed papers and the process followed, e.g., a PRISMA diagram, is necessary for the reproducibility of the methodology used.

AUTHOR: This is understandable, however, in creating a new model like this, no existing procedure was followed as this work is primary and custom and not a meta-analysis or review article. As much detail as possible was given in the article in terms of methodology, references and resources used, with an extensive supplementary list to ensure transparency. In addition, the figures provided aimed to ease the understanding of the process flow. Respectfully, I am unable to make further improvements at this point, yet my email address will be available in the final publication in which I can clarify further.

"S7: Percentage of raw material in final product, based on market investigations in Gauteng." This table

indicated that an average of 100% bovine milk was used in the finished product. This is a strong claim, and the need for more evidence or support could be provided. This table and other table findings should also be discussed if they align with existing research findings.
AUTHOR: I understand there was a misconception in what the percentages mean. Bovine milk, as available on shelf, have no added ingredients (unless clearly stated to be fortified with Vit D). Raw milk is processed as is to give us the milk on shelf thus the raw ingredient in milk is 100% bovine milk. There are no claims made, nor any references to percentage of milk solids or moisture levels in milk. This is merely mention of ingredients, in which case it is accurate. Therefore, I have clarified this in the text to avoid such misunderstandings. Thank you. Furthermore, since this is primary research and a newly created model which was theoretically tested, no discussion against existing findings could be made on further results tables as there is nothing to compare it to. This is a novel development, and more research is needed to validate the results further. However, a mention was made in the discussion in how the results compare with that of existing models such as the NRFi or LCAai. The tables in the supplement, if this is what you are referring to, are source tables or calculated tables. Therefore, no further discussion has been made. I trust this clarifies the purpose of the tables and article and that the discussions now present will meet your approval.
Due to the nature and high relevance of the paper to existing food systems, there is a need for direct, clear and actionable recommendations to relevant stakeholders. Also, inclusion of direct benefits in the policy should be included.
AUTHOR: Thank you. I appreciate this. The discussion has been adjusted to include this. I hope it meets your satisfaction
Relevant papers from 2023-2025 should be included, as recent research findings keep being updated in the papers. The papers from 2013 and below should be updated with more recent versions.
AUTHOR: Thank you, where possible and relevant to the production systems used, this has been done, However, major limitations in data-availability was found in the initial research and to date, since we need a full thread of data through all 3 parameters to accurately run the model. In addition, the earlier papers used was to assist in the methodological approach of the creation of the model. Due to financial and time constraints, I could not fully address this comment, as it would take a lot of time and research to rewrite the model to match 2023-2025 papers. Thus, your previous comment is extremely valuable as we need participation from stakeholders to validate this model and test it against real-life scenarios and more recent research, for which we need permission to use primary producer data. We are in the process of approaching producers to achieve this and will continuously improve the model as time and finances allows.
An addition on the justification of using almond, oat and soy beverages should be added. Also, the justification for bovine milk choices should be given.
AUTHOR: Thank you, this has been added.

Appendix 1: Original manuscript for review

An environment, economic and nutrient index for milk and plant-based beverages in South Africa

Abstract

Sustainable decision-making in the food sector is critical in addressing global challenges such as climate change, resource scarcity, and malnutrition. Particularly, the milk and plant-based beverage sector lacks a comprehensive sustainability index tailored to assess economic, nutritional, and environmental impacts. This study develops a specialized sustainability model for milk and plant-based beverages, adaptable to different countries. The Dairy Index for Environment, Economics, and Nutrition (DiEET) revealed that bovine milk scored 3.67 (nutritional), 0.161 (environmental), and 1.543 (economic); almond beverages scored 1.55, 0.172, and 1.103; soy beverages scored 2.21, 0.193, and 1.277; and oat beverages scored 1.204, 0.165, and 1. 083.These findings highlight the need to balance nutrition, economic viability, and environmental sustainability in food choices. The model, based on scientific data and requiring minimal user input, provides a practical tool for stakeholders to assess and compare sustainability across products. By enabling informed decision-making, this study promotes a more sustainable future, advocating for practices that consider all dimensions of sustainability in the food sector. Continuous refinement and validation of the model are essential to maintain its relevance amid evolving data and industry practices, ensuring its effectiveness in guiding stakeholders towards sustainable dietary choices.

Significance

This study provides a comprehensive sustainability index for milk and plant-based beverages, addressing critical gaps in current assessments. By integrating environmental, economic, and nutritional indicators, the Dairy Index for Environment, Econo mics, and Nutrition (DiEET) offers a holistic approach to evaluating food products. The findings highlight the trade-offs between nutritional quality, economic viability, and environmental impact, emphasizing the need for balanced decision-making in agricultural production. This model serves as a practical tool for stakeholders, promoting consumer education and guiding industry practices towards sustainability. Its application can enhance sustainability evaluations and contribute to global efforts in monitoring sustainable development goals.

Keywords: Sustainability index, nutrient index, environmental footprint, plant-based, milk

Tables, figures and supplementary material inserted at the end of the document.

Introduction

In the face of global challenges such as climate change, resource depletion and nutrient distribution imbalances, sustainable decision-making in the food sector has become a pressing concern[1,2]. The global food supply, while generally meeting demand, still suffers from inefficiencies like food waste, logistical issues and affordability constraints, impeding equal access to nutritious food[3,4,5,6.] This issue is particularly acute in the dairy industry and plant-based beverages (PBBs), where the need to balance environmental, economic and nutritional aspects is paramount. Current methods of assessing the sustainability of dairy and PBBs often lack a holistic perspective[7]. Standard labelling and nutrient profiling systems, while informative, do not capture the overall healthfulness of products. This gap is notable in the absence of specific nutrient indexes for dairy foods or proteins. Moreover, environmental sustainability assessments relying on single-metric results from life cycle analyses (LCAs) tend to oversimplify the complex sustainability landscape[8]. These challenges underscore the necessity for more detailed and context-specific sustainability evaluations that consider various production systems, geographical locations and broader impact metrics beyond carbon footprints.

South Africa faces unique challenges regarding nutrient deficiencies and changing consumer and market trends, which can have adverse effects on vulnerable populations, particularly the poor and malnourished[9,4.] Rapid shifts in dietary preferences, influenced by global trends, local economic conditions and consumer trends which alters the nutritional landscape, can potentially exacerbate nutrient deficiencies and health disparities[10]. The dairy industry and the emerging market for PBBs are central to these changes, making it critical to understand and assess their sustainability in the South African context. This study aimed to develop a tailored sustainability index for milk and PBBs in South Africa, evaluating environmental sustainability, economic viability and nutritional impact in a manner specific to the industry and country. By addressing the complexities of sustainability within the South African dairy and PBB industries, and integrating nutritional, environmental and socioeconomic indicators, this initiative seeks to foster informed consumer choices, enhance industry resilience and ensure long-term sustainability. The goal was to create a comprehensive evaluation framework that prioritises simplicity, replicability and thus transparency and education for both consumers and producers.

Research method

A systematic and comprehensive literature review was undertaken to conduct a data analysis on the subject of sustainability and sustainability modelling. Databases such as ResearchGate and Google Scholar were systematically searched for peer-reviewed articles, research reports and studies published over the past two decades (2000–2023), encompassing the indicators mentioned (i.e., nutrition, economics and the environment) related to the sustainability of milk and plant-based beverages, as well as how these indices were measured. Peer-review methods of measuring the indicators were identified and adopted according to the aims of this study. Subsequently, an index named Dairy Index for the Environment, Economics and NuTrition (DiEET) was developed to comprehensively evaluate the environmental, nutritional and economic profiles of milk and plant-based beverages. The development of the model is elaborated in the next section and the process flow can be seen represented in Figure 1.

Model development overview

The Nutrient Rich Food (NRF) index, proposed by Drewnowski et al.[11] and later adapted by Drewnowski and Fulgoni[12] to the NRFh (hybrid), which includes nutrients to be encouraged and makes provision for adherence to recommended food groups, served as a foundational principle guiding the current model. Additional refinements were made such as in the NRF for adequate intake (NRF-ai), which incorporates the prevalence of inadequate and excessive nutrient intake within populations, by means of weighting factors and subgroups to measure intake according to stratified population requirements[13]. In addition to this, digestible indispensable amino acid score (DIAAS) values inspired the inclusion of protein quality[14]. Beal et al.[15] discussed the concept of priority micronutrient density in foods as a basis of classifying foods in terms of their supply towards recommended intakes of key identified priority nutrients. The Delta Model® as developed by the Sustainable Nutrition Initiative[16] uses supply of nutrients to deliver an understanding of food groups within the food system. These methodologies provided the foundational framework for the nutritional component of the DiEET model, shaping the implementation of the approaches taken, along with adaptations and refinements to suit a South African context.

The environmental component, being recognised as a sustainability indicator globally, is incorporated into the sustainability index as a key component by means of focusing on major contributing indicators such as land use, electricity usage, efficiency, waste and water use[17,18,19]. Records of expenditures are maintained on farms and factories, whether by automatic management tools or manually by perusing invoices or weighbridge slips. Thus, the model was built with the goal to leverage existing data for evaluating environmental impact as a midpoint between precision of data and data availability as provided by farmers. Ideally, thorough life cycle analyses (LCAs) would be used for all relevant farms, yet a simplified method was used for the purposes of the model which accounts for a more realistic and industry-level availability of data[20]. This method entailed the use of shared indicators among distinct products and processes, despite differences in farming operations, and relying on data that is generally measured in everyday practice. From an economic perspective, the model incorporated consumer cost as a factor which was evaluated against the poverty levels of the entire population, considering various income groups in South Africa. In addition, the economic health of the producers was assessed by revenue, employment rates and contribution to gross domestic product (GDP)[21].

Data collection

In order to populate the model, as well as adapt indicators to be relevant to South Africa, both peer-reviewed sources and local online databases were used to source the most relevant information on local population demographics, nutrient requirements, prices and more. Comparisons and scenarios previously drawn to compare the nutrient profiles of milk and plant-based beverages were used to populate comparisons[22,23,24,25,26,27]. Local market reports and scrutiny of local supplier websites offered guidance in terms of which studies and datasets were most applicable, e.g. most of South African almond milk is produced using almonds from California, hence Californian LCAs were used to draw information on the respective indicators[28]. Similarly, data on oats is rarely available in South Africa thus data from wheat crops needed to be inferred[29,30,31]. Industry members and local processors were consulted for guidance as well, however, due to non-disclosure agreements with the industry members the exact data collected were only used for guidance purposes. Literature-based sources were mostly used to compile hypothetical scenarios, solely to validate the efficacy of the model and provide guidance pertaining the different parameters employed.

After writing the first draft, ChatGPT version 4.0, Open AI was used for an initial language screening, or to shorten lengthy sentences using the following two prompts "Correct the language and grammar in this paragraph: [inserted paragraph]" or "Shorten this text to 50 words: [inserted text]." All resulting text was revised for accuracy before inclusion and submission to an official language editor.

Model outline

The DiEET model is a first iteration of a conceptual SiEEN (Sustainability index for the Environment, Economics and Nutrition) model which currently applies only to dairy and potential alternatives. The model does not use the traditional expression of a single score for sustainability, but rather scores each component separately, to avoid masking of a poor score for one indicator with a good score of another indicator. The three scores are expressed by means of shorthand notation. The notations as follows will be used: NS = nutrient score; ps = protein score; EnS = environmental score; EcS = economic score. To simplify the interpretation of the results, the environmental and economic components were inverted to allow all increasing values to be favourable. The components are summarised in Figure 2.

Nutrient component

Based on the core nutrients highlighted by the NRFi and NRFh models[12,32], as well as the suggested nutrients to be included in nutrient indexing by Beal et al.[15], the nutrients included in the model were potassium, dietary polyunsaturated and monounsaturated fats (PUFA+MUFA), saturated fats, iron, sodium, magnesium, calcium, protein, vitamin B12, vitamin E, vitamin A, folate (vitamin B9), and zinc[11,12,15]. Fibre and vitamin C were deliberately excluded due to its natural absence in dairy[33]. Additionally, due to its relevance in the functioning of calcium, e.g., in the mineral complex formed during bone formation, phosphorus was included. Vitamin B2 was further included due to the prevalence of deficiencies in developing countries such as African countries[34]. Amino acids were included as individual nutrients but were also considered as a subcomponent of protein quality in a separate sub-score. The above were expressed as content per 100 ml, as a percentage of the population nutrient requirements as reported in Supplementary Table S5., however, the values were not capped at 100% DV as with the NRFi[11,14,35].

The nutrient requirements in Supplementary Table S5 were synthesised from different sources to synthesise daily recommended intakes[36,14,37], with some supplementation from more recent epidemiological studies in terms of protein and fat intake[38]. Energy requirements are based on moderate physical activity i.e., a physical activity level factor of 1.8, and average extra daily requirement for the whole pregnancy[36]. Considerations were given to specific requirements within each age and sex group, such as being pregnant or ill[39]. To manage lactation data challenges, pregnant and breastfeeding women are grouped together, with pregnancy assumed to last 9 months and lactation 3 months. In cases of non-lactation, higher nutritional demands were considered throughout postpartum recovery. Due to their marginal impact, multiple births were excluded, with the nutritional needs of such cases assumed equivalent to non-pregnant women. Recommendations were adjusted based on population age and sex demographics, as reported in Supplementary Table S1, including the percentage of pregnant or lactating women as calculated in Supplementary Table S2 to estimate average nutritional requirements. Fortified nutrients, important for sustainable food systems and common in products, were not excluded.

The subscores and subsequent formulas employed are summarised in Table 1. Weighting factors were applied to the nutrients based on existing deficiencies in supply, where a deficiency in the supply of a nutrient warrants an increase in weighting of the nutrient, as calculated by the supplementation coefficient (Sc), which is based on Supplementary Table S6 [16]. Iron, vitamin A and zinc were exceptions, where local deficiencies surpass global deficiencies and the prevalence of deficiencies in adolescents were used, thus 29%, 42% and 63%, respectively[40,41,39]. Similarly, a weight factor (contribution coefficient) is assigned to each product based on the fraction that each food group (1. milk, excluding butter; 2. soybeans; 3. nuts and products; and 4. oats) contributes to global supply of a specific nutrient, which is then adapted to the percentage of each raw material in the final product, as reported in Supplementary Table S7 and Supplementary Table S8. Protein quality (protein score or ps) is assessed as an additional score by calculating the indispensable amino acid score (IAAS) of each amino acid and, contrary to DIAAS in which only the most limiting amino acid is highlighted, summed for a total view of protein quality[14,42,43]. The amino acid scoring pattern has been adapted according to demographic strata as reported in Supplementary Table S4.

The NRFh utilisation of My Plate Food Groups have been replaced with the latest PURE Healthy Diet recommended intakes (g/day) of each food group in the healthy diet contribution coefficient (HDCc)[12,38], i.e., legumes (48g/day), nuts (28.20g/day), dairy (185.50g/day) and whole grains (40.90g/day). Additionally, based on recent research on saturated fat and latest insights on the food matrix effect pertaining saturated fat, the limiting nutrient score (LIMz) have been removed[44,38]. Limiting factors employed were sodium content, sugar content and associated diseases or allergies, with some adaptations as follows: sugar content was used to calculate the glycaemic index coefficient (GIc), which penalises a food based on high glycaemic index (above 55) or low glycaemic index (below 55), based on the type of sugar present in the food e.g., sucrose (GI:65), maltose (GI:105), lactose (GI:46)[45,46]. Sodium was either a limiting or a contributing nutrient, depending on the content per standard serving, in order to avoid deficiencies of sodium. In the adjusted sodium level (Sodium(adj)) an upper limit was imposed where sodium was limited (deducted) from the nutrient score if the distance from target exceeds 50%, i.e., if the content was more than 50% of the recommended daily intake, and contributed positively to the score when the sodium content was 49% or less[47]. An exclusion threshold was applied, based on the prevalences of allergies or intolerances to each product type, such as reported in Supplementary Table S3. The full equations and sub-scores are in Table 1.

Environmental component

The common and major contributing indicators identified to be of importance in environmental footprint assessments were blue water (i.e., service and ground-water), fertiliser, fuel, pesticide and land use[18,29]. Although not all encompassing, these indicators offer a general idea regarding the impact on emissions, water use, eutrophication or acidification potential. All inputs were adjusted to weight or litre (in the case of raw milk or final product) and adjusted for percentage raw material in the final product during the final calculation. On farm and factory level, an additional point-system was employed as a qualitative measure of the longevity and sustainability of the production system, such as the frequency of soil analyses, cropping type (e.g., mono-cropping or regenerative), the frequency of sustainability assessments and others[49]. A simplified scale approach assigned points to the variant applied within each of these indicators, recognising varying degrees of environmental impact or benefit in each of the qualitative measures. A summary of the indicators and user-input required is presented in Table 2., in which quantitative scores awarded point from 0.06 or 0.05 to 0.01, with higher score being less favourable. These inputs, along with the scenarios in Supplementary Table S9, were used in the calculations summarised in Table 3 to contribute to the final environmental score.

Economic component

Inspired by the NRFPI, price was a key component in the economic score[50]. In the current economic score, price of a product was adapted according to local poverty lines and the amount a person within the poverty levels has each day for food into poverty-adjusted prices[7]. The poverty levels a, b and c account for 18.9%, 37.60% and 57.10% of the population which have R22.10, R29.67 and R44.5/ca/day for food, respectively[4,37]. An additional poverty level (diet-bound poverty level) was created to account for 65% of the population unable to afford a healthy diet, with R57.13 to their availability which was adapted from a recent publication by Ederer et al.[51] on purchasing power parity base[37,52]. Additional inputs for both farm and factory levels included 1) gross profit, 2) wages, 3) taxes, 4) subsidies, 5) expenses, 6) income from repurposing by-products or waste, 7) employee numbers, and 8) production potential. These were used to assess, among others, the extent to which a producer contributes to the gross domestic product (GDP) of South Africa and to the workforce, as well as the overall financial health of the producer[21,53]. The calculations employed are reported in Table 4.

Model implementation

Nutrient profiles sourced from literature comparisons[22,23,24,25,26,27] and previous local nutrient analysis data[54] were used to compile the varying scenarios for a nutrient comparison as reported in Table 5. Protein quality could only be assessed from locally sourced data as sufficient published literature was unavailable. The main subscores and final nutrient score (NS) are visible in Table 5., with the full nutritional score outline used reported in Supplementary Table S10.1.

The quantitative inputs used in the environmental score were inferred from literature scenarios as follows: 1) oat and soybean which are regeneratively produced, based on published available data, although not representative of all production systems in South Africa; 2) dairy production, based on pasture-based systems which represent a large majority of South Africa's production systems[55] and 3) conventionally produced almonds from California, representing 75% of globally produced almonds, including majority of brands in South Africa[28,56] .On the processor level, some adaptations have been made to be representative of a South African production system where a single processor is responsible for multiple beverage types.

Qualitative measures were purely hypothetical and have been kept close to similar in all products to avoid incorrect portrayal of results. Table 6 reports the main subscores. Major differences included between scenarios were only in the cropping type and use of livestock, where bovine milk utilised cover-cropping and pasture-based systems; almond production used mono-cropping without post-grazing or integration of livestock, but used chicken manure and therefore has been indicated as post-harvest grazing in the form of manure spreading; soy used rotational cropping and no livestock; and oat milk utilised regenerative agriculture and post-harvest grazing. The quantitative scenarios and numerical inputs used are reported in Supplementary Table S9, based on inputs and outputs per year, whereas the full environmental score outline used is tabled in Supplementary Table S10.2.

Pertaining the economic score, large data gaps and differences between local and international datasets lead to insufficient data to populate the model. Hence, a decision was made to focus on locally available information (which is retail price), preventing skewed results. To scrutinize the effect of price on the economic score, a hypothetical scenario was thus created in which the same producer processes milk and plant-based beverages, with results reported in Table 7. All other factors remained equal across all products, with retail price being the only differing factor. The fourth (diet-bound) poverty-level was selected for the comparison of retail price. The economic component outline is reported in Supplementary Table S10.3.

The results of the main scores (excluding protein score) according to the DiEET model, are visualised below in Figure 3. In viewing the relationship between each component to one another, it is clear that a trade-off exists between the scores when aiming to achieve high score on more than one parameter When comparing each score of the plant-based beverages, as a percentage of that of bovine milk in Figure 4., a clear relationship emerges in which the magnitude of differences between nutrition score and economic score emerges, as well as the direction and component in which bovine milk needs to improve.

Discussion

The developed model, including nutritional, environmental and economic scores as separate indicators, offer variations and scope beyond standard measures such as the NRFh[12], NRFPI[50], nLCA[8] or other single-metric indexes. This is in general a deviation from common practice and can provide opportunity for transparency in consumer decision-making and education. The environmental footprint simplifies comparisons by focusing on key indicators of environmental footprint rather than a single environmental footprint. On one hand, this is an improvement to standard measures such as an LCA[8] as it represents a broad range of outcomes other than carbon footprint, specifically considering the ongoing debate regarding the use of carbon dioxide equivalents in current metrics[30,57]. It further allows for industry application by farmers and producers, due to the simplicity of data required.

In the DiEET model results reported in Table 6, mostly similar trends in environmental scores (ES) compared to standard units of measure were observed. Notably, the ES of bovine milk was consistently lower than all plant-based beverages. Factory inputs for the environmental score remained similar, especially in cases where processors handle both milk and plant-based beverages on the same production line. However, it is essential to acknowledge that raw material processing, which typically occurs off-site for plant-based beverages, is not fully represented in the ES calculation and may be underrepresented. This highlights a data gap and the potential for increased industry collaboration and data-sharing. Yet, it underscores the improvement required in better reporting on matters such as carbon sequestration, as well as overall decrease in environmental footprint of bovine milk.

The DiEET nutrient score (NS) in Table 5, both as a subscore and in the final score after accounting for additional health factors, indicated that bovine milk offers a more favourable nutrient profile. This aligned with nutrient profiling but provided less variation than the NRFi, as results using the NRFi is largely dependent or influenced by fortification. Protein quality, as assessed by protein score, however, showed that soy beverage contained more amino acids per gram of protein than bovine milk or other plant-based beverages, although per 100 ml this might was not the case. This suggests that soy beverage could serve as a valuable protein supplement when considering gram-to-gram protein quality. It further sheds light on the limitations in the use of DIAAS which does not provide an indication of the overall dietary supplementation that could be achieved by a product but solely focuses on digestibility, neglecting that amino acids in their singular form could act as supplements to an otherwise lacking diet[14]. The model also provided a broader and country-specific contextualised view of the nutrient profiles of milk and plant-based beverages.

From an economic perspective, the model results in Table 7 suggested that bovine milk has a more favourable economic score compared to other beverages when only taking affordability into account, making it more affordable for a larger portion of the population. Based on the nutritional score, this consequently allows for more affordable, high-quality nutrition. Although hypothetical data was used to populate the remaining values in the economic scores, the economic score in general provides a holistic view of economic sustainability by taking both consumer affordability and producer viability into account. Application in industry and consequent validation of these results with ground-truth data can provide further insights into the results and trends reported in this study.

As is, the model is a stepping-stone towards more holistic and transparent sustainability measures, recognising that the scientific accuracy and data supporting the model requires more in-depth research and validation. Ideally, in subsequent iterations of the intended SiEEN model, subscores would apply where e.g., each production system (crops, livestock, mixed, intensive, extensive,) has their own analysis which contributes to the final scores.

Additional datasets need to be collected to validate the model and gain accurate results, as well as measure the alignment with current methods and trends to prevent any form of bias generated by the model. The model's complexity requires careful interpretation, but it offers a holistic approach to sustainability assessments. The model serves as a potential tool for decision-makers in the food industry, researchers and policymakers, as well as consumer educators, emphasising the need for ongoing efforts to create a more sustainable future for food production and consumption.

Critical evaluation

Limitations in the model exist due to multiple factors such as the omission of nutrient bioavailability[58], which was an initial goal yet requires much more extensive research to include accurately. Limited research is currently available on the contribution of plant-based beverages to global nutrient supply; hence, over or underestimations are possible and require verification when considering the current weightings applied to nutrient supply and contribution of plant-based beverages.

While the NRFh approaches used provide a useful framework for evaluating the nutrient density of foods, its application is limited by the inability to fully capture the complexities of individual dietary needs and the synergistic effects of whole diets. This model, focused on quantifying the nutritional value of single food items, overlooks the broader context of dietary patterns and the interplay between different foods and nutrients that influence health outcomes. Consequently, it may not adequately address the variability in nutritional requirements among individuals or the holistic nature of dietary health. Future research should, therefore, pivot towards exploring the impacts of whole diets and food groups within these diets to offer more comprehensive and personalised dietary recommendations.

From an environmental perspective, although requiring simplified data, the model risks oversimplification of the environmental impact of products and requires large-scale studies to verify the relationships between these indicators with outcomes such as eutrophication potential, acidification or biodiversity loss. This is especially relevant to the qualitative measures employed in the environmental component in which a scaling point system is used in equal intervals, whereas ground-truth data may indicate that the scaling intervals change according to different size intervals or based on the environmental impact of each production system (such as regenerative in comparison to conventional).

In the economic component, verification is lacking in the results observed, particularly from a processor level and consequently requires further research to investigate the relevant economic parameters more in depth. The lack of information from a processor perspective further eliminates room for comment on the success of the measures of economic perimeters other than affordability.

Statistically, the model results are limited due to the availability of local data and consequent verification thereof. Thus, the results only provide an indication of whether the model can be implemented in industry, based on the general trends observed in the results and how well it compares to that found in the literature. The results should not be reported as definitive indications of the sustainability of milk and plant-based beverages. In future, the application of the model and collection of ground-truth data will provide sufficient datasets to validate the model and the results from an industry perspective and a statistical perspective.

Conclusion

The DiEET model's approach has advanced the existing understanding of the sustainability of bovine milk versus plant-based alternatives like almond, soy and oat beverages. This research emphasised the need for a holistic view of sustainability, incorporating nutrient density, bioavailability, environmental impacts through comprehensive life cycle assessments, and the socioeconomic implications for food security in South Africa. It further indicated the potential trade-off to be made between environmental sustainability and nutrient density or affordability, however, shed light on the potential for the dairy industry to reduce its environmental impact. This is relevant to all beverages, as the use of regenerative practices had a clear impact on the final environmental score. In the aim towards sustainable food systems, the necessity for collaborative research, policy innovation and informed decision-making is underscored, offering a foundation for future strategies to enhance food system resilience and equity globally.

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Tables

Table 1: Nutrient score formulas and subscores

Element	Formula
Nutrient Sufficiency Score (NSs)	NSs =Sum [(Nutrient content / Stratified nutrient requirements) x Sc x Cc]
Supplementation coefficient (Sc)	Sc = 1 + (shortage/population nutrient requirements)
Contribution coefficient (Cc)	Cc = 1 - (contribution ratio)
Protein Score (ps)	ps = (Sum (IAA))/10
Healthy Diet Contribution coefficient	HDCc = recommended intake/ 100
Glycaemic Index coefficient (GIc)	GIc = sugar content/100 x [(GI – 55) / 100] Note only if GI >0; if <0, GIc - 0
Sodium (adjusted)	Sodium (adj)= (Target Sodium Content/(Sodium Content x serving size), serving = 120ml (Schonfeldt, 2020)
Exclusion Threshold coefficient (Etc)	Etc = 1 - Sum [Allergy prevalence for product x % of raw material in final product]
Nutrient Score (NS)	NS = NSs + HDC – GI corr Added Sugar – GI corr Natural Sugar -/+ Sodium(adj)

Table 2: Environmental score user inputs

Farm and factory inputs	**Farm only inputs**
Product yield	Fertiliser use
By-product yield	Pesticides use
Quantity recycled	Cropping type (mono < rotational <inter <cover <regenerative < agroforestry)
Quantity repurposed	Livestock use (mixed pasture < single pasture < TMR + fodder carry, post-harvest grazing < TMR (no fodder carry) < none)
Production potential	Soil type (sandy < clay < loam < silt < peat)
Fuel use	Soil test frequency (never < 5–10y < 2–5y < yearly < 2xyear)
Electricity use	Water test frequency (never < 5–10y < 2–5y < yearly < 2xyear)
Blue water use	Crop health / livestock welfare assessment (never < 5–10y < 2–5y < yearly < 2xyear)
Sustainability training or education frequency (never < 5–10y < 2–5y < yearly < 2xyear)	**Factory only inputs**
Improvement in efficiency yearly (none < 1–2% < 2–5% < 5–10 % < 10%+)	Not 100% recycled packaging used
Input reduction yearly (none < 1–2% < 2–5% < 5–10 % < 10%+)	

Table 3: Environmental score formulas and subscores

Element	Formula

Farm Productivity Score (FPs)	FPs = Net yield – potential lost – net land use
Potential lost	Production potential - yield
Net yield	Repurposed by-produced + yield
Net land use	1/net yield
Farm Footprint Score (FFs)	FFs =[sum(input per hectare)/net yield]/1000
Farm Management Score (FMs)	FMs = Sum of qualitative management indicator points
Farm Environmental Score	FEs = (FFs x % raw material) FPs + FMs
Factory Footprint Score (FFs)	FaFs =[sum(input)/net yield]/1000
Factory Management Score (FMs)	FaMs = Sum of qualitative management indicator points
Factory Environmental Score	FaEs = FaFs + FaMS
Environmental Score (ES)	ES = 1/(FaEs + FEs)

Table 4: Economic score formulas and subscores

Element	Formula
Poverty Factor (Pf)	Pf = (Poverty line a, b, c, or d / 3 meals)
Poverty Adjusted Price (Pap)	Pap = R/100ml x pf
Producer GDP contribution	(Gross profit + wages + taxes – subsidies) / agriculture GDP contribution (2.7%)
Cost of production	(Expenses – Income from repurposing materials) / total production Income from production = Gross profit/Total production
Cost:Income factor	(Cost of production/Income from production)/10
Workforce contribution	((number of employees / agricultural employment number (840 000) x 100) x (1 + unemployment rate (32.90%)
Potential lost	[(Production potential – Total production)/ Production potential] /100
Economic score (producer or processor)	ES (producer or processor)= GDP contribution – Cost:Income ratio – Potential lost + Workforce contribution
Economic score total	ES =1/(ES producer + ES processor – Pap)

Table 5: Nutrient score comparison

		Local data analysis	Local label info	#1 Lit. scenario	#2 Lit. scenario	Average
BM	NSs	1.993	1.938	1.970	1.789	1.932

	ps	1.186				
	NS	**3.771**	**3.679**	**3.713**	**3.525**	**3.672**
AM	**NSs**	0.740	1.321	1.103	1.755	1.230
	ps	0.909				
	NS	**1.088**	**1.626**	**1.391**	**2.084**	**1.547**
SB	**NSs**	1.301	1.848	1.1310	2.237	1.629
	ps	1.257				
	NS	1.854	2.377	1.863	2.73	**2.206**
OB	**NSs**	0.521	1.158	0.758	0.626	0.766
	ps	0.795				
	NS	**0.971**	**1.583**	**1.206**	**1.057**	**1.204**

Scenario: 1) Local primary analysis (Maree et al, 2023) 2) South African products' label information (Maree et al., 2023), supplemented with local primary analysis results; 3) Literature results, supplemented with local results (Smith et al., 2022b; Walther et al., 2022) 4) Literature results, supplemented with local results (Fructuoso et al., 2021).

Table 6: Subscores and environmental score results of bovine milk and plant-based beverages

Parameter	**BM**	**AB**	**SB**	**OB**
Farm productivity score	0.911	0.403	0.427	0.724
Farm footprint score	0.001	0.080	0.004	0.000
Management score	0.290	0.765	0.290	0.310
1) Farm environmental score	1.203	2.250	0.722	1.034
Factory footprint score	4.859	4.905	4.866	4.870
Management score	0.130	0.130	0.130	0.130
2) Factory environmental score	4.989	5.035	4.996	5.000
Environmental sub-score	6.192	5.799	5.171	6.034
Final environmental (inverted) score	**0.161**	**0.172**	**0.193**	**0.165**

Table 7: Comparison of retail price effect in the economic score results of bovine milk and plant-based beverages

Parameter	**Bm**	**Ab**	**Sb**	**Ob**
Price for reference poverty level:	0.130	0.389	0.265	0.405

RM: GDP contribution	0.229	0.229	0.229	0.229
RM: cost/income ratio	0.31	0.31	0.31	0.31
Raw material producer economic score	-0.08	-0.08	-0.08	-0.08
RM: GDP contribution	0.728	0.728	0.728	0.728
RM: cost/income ratio	0.13	0.13	0.13	0.13
Processing producer economic score	0.6	0.6	0.6	0.6
Economic sub- score	0.648	0.907	0.783	0.923
Final (inverted) economic score	1.543	1.103	1.277	1.083

Figures

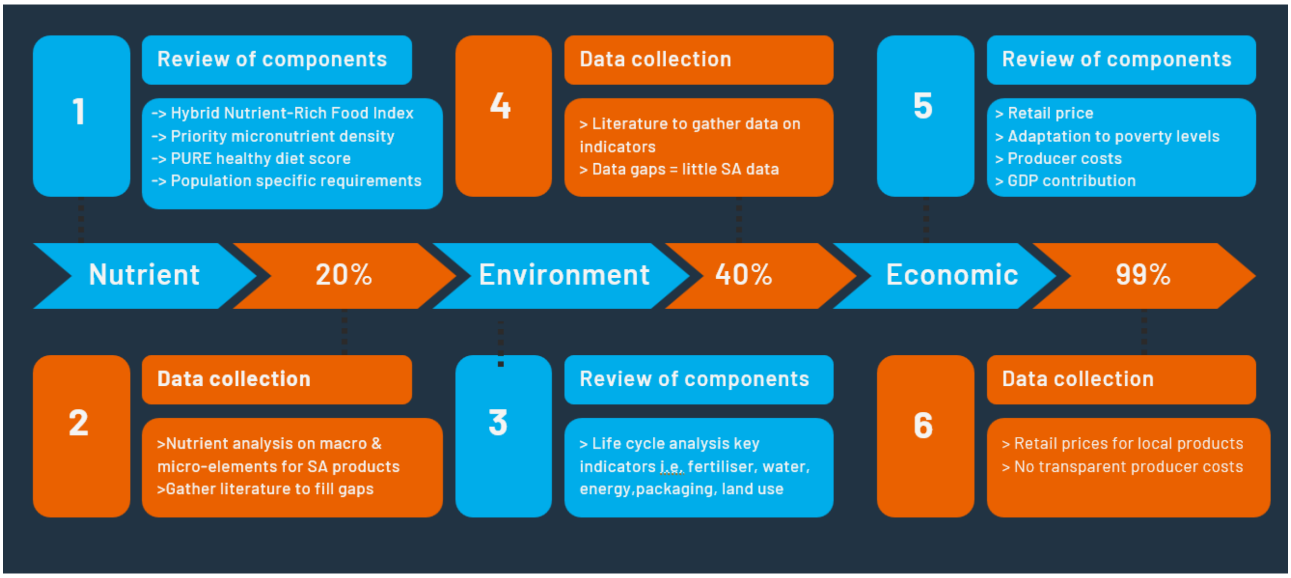

Figure 1: Model development overview and components included

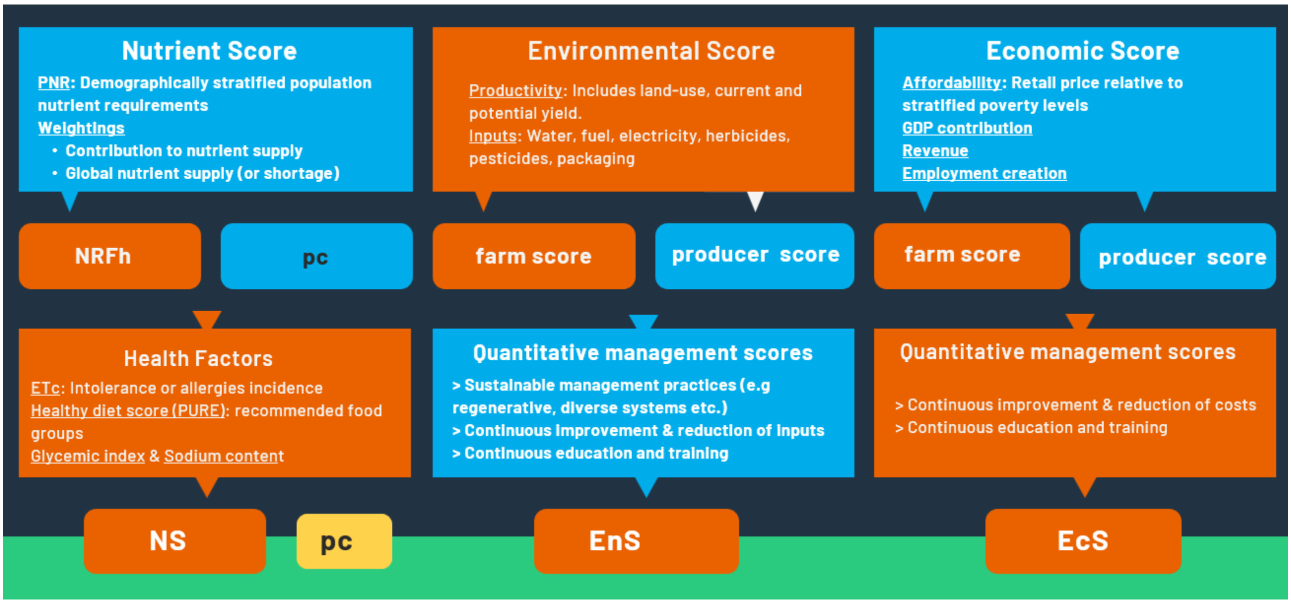

Figure 2: Model outline and summary of main factors included

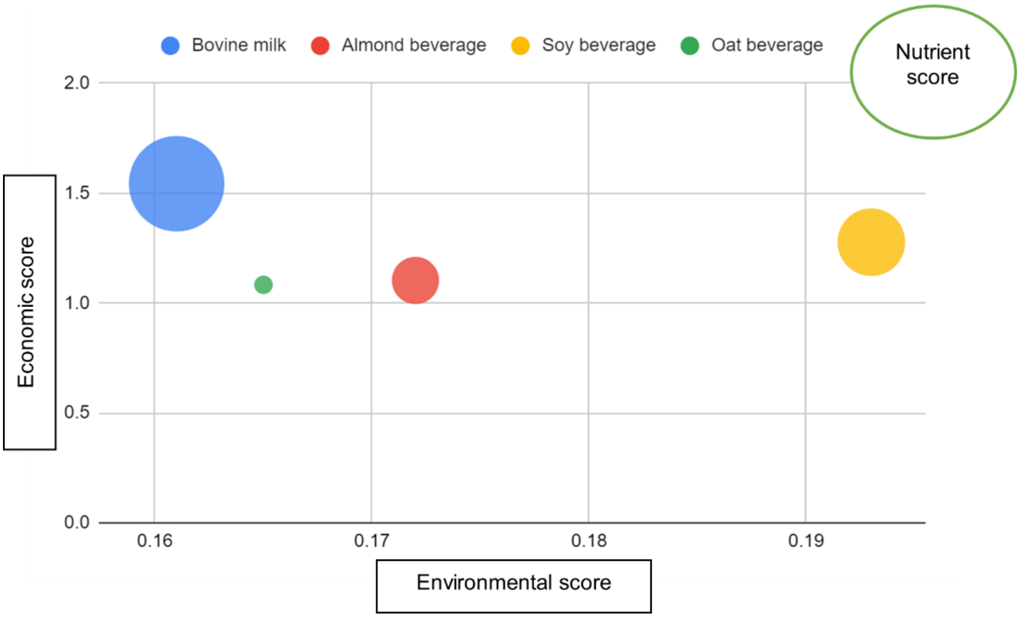

Figure 3: DiEET results for bovine milk and plant-based beverages (bubble size: nutritional score)

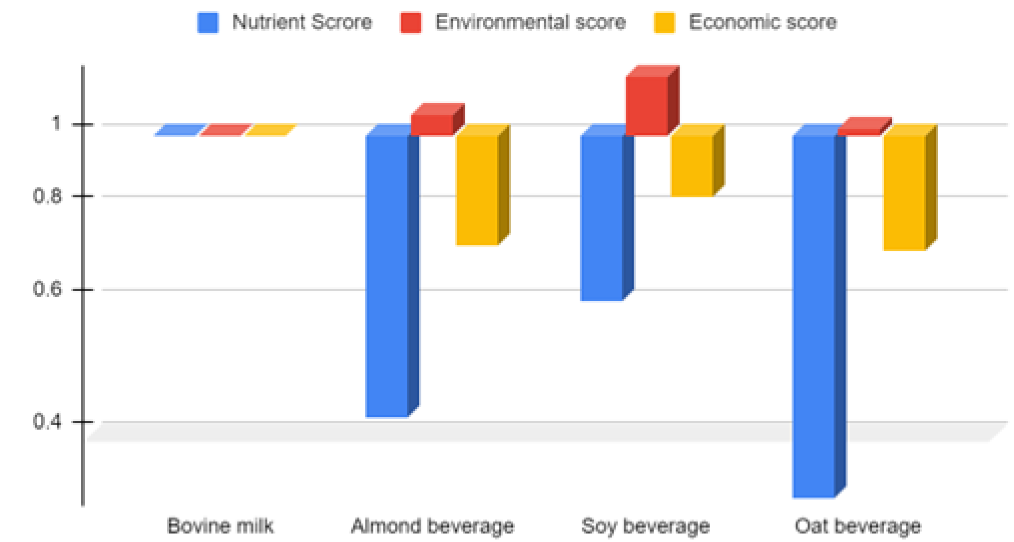

Figure 4: DiEET results of plant-based beverages in relation to bovine milk

Supplementary material

S1: South African population, age and sex distribution (including the nutrient brackets each category was applied to) (Statisa,2022)

Age (Daily recommended intake bracket)	Male	%	Female	%
0–4 (0–3, divided equally)	2 884 691	4.76%	2 809 831	4.64%
5–9 (4–8)	2 837 833	4.68%	2766 037	4.56%
10–14 (9–13)	2 890 269	4.77%	2 824 108	4.66%
15–19 (14–18)	2 566 719	4.24%	2 534 956	4.18%
20–24 (19–30)	2 351 752	3.88%	2 327 273	3.84%
25–29 (19–30)	2 626 342	4.33%	2 577 765	4.25%
30–34 (30–50)	2 833 963	4.68%	2 761 813	4.56%
35–39 (30–50)	2 583 697	4.26%	2 546 286	4.20%
40–44 (30–50)	1 990 106	3.28%	2 043 181	3.37%
45–49 (30–50)	1 607 584	2.65%	1 699 172	2.80%
50–54 (50–70)	1 262 718	2.08%	1 419 523	2.34%
55–59 (50–70)	999 048	1.65%	1 261 065	2.08%
60–64 (50–70)	777 905	1.28%	1 068 241	1.76%
65–69 (50–70)	578 724	0.95%	858 302	1.42%
70+	833 531	2.81%	1 482 557	4.79%

S2: South African birth numbers and percentage of pregnancies per age group

Birth rate	1.79%
Number of births	1 087 526
% of females	3.51%
Age groups	Percentage pregnancies per group
10–19 (14–18)	13.12%
20–30	47.00%
30+	39.88%

Sources: statssa.gov.za (2021); Statista (2022)

S3: Global allergy and disease incidence specific to milk and plant-based beverages

Allergy or disease	Product	Prevalence (fraction)
Milk allergy	Milk	0.005
Maltase-glucoamylase deficiency	Oats	0.020
Sucrase-isomaltase deficiency	Soybean	0.001
Almond nut allergy	Almond	0.010
Soybean allergy	Soybean	0.017
Lactose intolerance*	Milk	0.810

Sources: Wiederstein et al. (2023); Qi and Tester (2020); Mandalari and Mackie (2018); Ahn et al. (2003); Storhaug et al. (2017)

S4: Amino acid scoring pattern, adapted to yield a population scoring pattern

Amino acid	IDc	Infants	1-2yrs	3-10yrs	11-14yrs	15-18yrs	>18yrs	Population scoring pattern

His	0.900	20.0	18.0	16.0	16.0	16.0	15.0	16.21
Ile	0.910	32.0	31.0	30.0	30.0	30.0	30.0	31.27
Leu	0.920	66.0	63.0	61.0	61.0	61.0	59.0	62.29
Lys	0.940	57.0	52.0	48.0	48.0	48.0	45.0	48.41
Met + Cys	0.860	27.0	25.0	23.0	23.0	23.0	22.0	23.48
Phe + Tyr	0.890	52.0	46.0	41.0	41.0	41.0	38.0	41.28
Thr	0.850	31.0	27.0	25.0	25.0	25.0	23.0	24.97
Trp	0.770	8.5	7.0	6.6	6.6	6.6	6.0	6.55
Val	0.900	43.0	41.0	40.0	40.0	40.0	39.0	41.03

Source: FAO (2013); CVB feed table (2016: Table 4.3); Reynaud et al. (2021)
Note: nearest age group percentiles used.; IDc = Ileal digestibility coefficient

S5: South African nutrient requirements based on demographic strata (PNR: population nutrient requirement)

Nutrients	Unit	PNR Total
Energy	kJ/d	10 494.30
Carbohydrates*	g/d	354.42
Fibre	g/d	28.51
Protein*	g/d	108.09
Fat*	g/d	75.44
- PUFA*	g/d	15.31
- MUFA*	g/d	26.44
- Omega 3 (alpha l)	g/d	1.28
- Omega 6 (lin)	g/d	12.99
- Sat fat*	g/d	24.77
- Trans fat	g/d	2.76
Potassium (K)	mg/d	2 799.84
Iron (Fe)	mg/d	12.73
Sodium (Na)	mg/d	1 381.29
Magnesium (Mg)	mg/d	321.73
Calcium (Ca)	mg/d	1 064.09
Phosphorous (P)	mg/d	723.21
Vit A	µg /d	794.60
Vit B2 (Riboflavin)	mg/d	1.13
Vit B12	µg /d	2.20
Vit B9 (Folate)	µg /d	379.46
Vit D	µg /d	15.63
Vit E	mg/d	13.92
Zinc	mg/d	9.06
Iodine	µg /d	157.96
Amino acids	mg/d	
- Histidine	mg/d	1 659.90
- Leucine	mg/d	6 446.57
- Lysine	mg/d	4 972.00

- Methionine (+cystine)	mg/d	2 416.50
- Threonine	mg/d	2 557.22
- Tryptophan	mg/d	735.83
- Isoleucine	mg/d	3 247.26
- Phenylalanine (+tyr)	mg/d	4 220.12
- Valine	mg/d	4 250.95

*Dietary Reference Intakes (DRIs) and FAO (2013); Amino acids are adapted according to scoring patterns and protein requirement; *Macro requirements based on PURE Healthy Diet (Mente et al., 2023); Energy based on moderate physical activity and average extra daily requirement for the whole pregnancy; M: male, F: female, P/L: pregnant and/or lactating*

S6: Global nutrient supply of nutrients based on the 2020 baseline setting of the Delta model (SNI, 2022) in relation to population nutrient requirements (PNR).

Nutrient	Unit	Supply*	Daily requirement	Supplement needed
Energy	kJ	11 208.98	10 494.30	-714.68
Carbohydrates	g	401.51	354.42	-47.10
Fibre	g	26.26	28.51	2.25
Protein	g	64.62	108.09	43.46
Fat	g	83.80	75.44	-8.36
Potassium (k)	mg	3 239.47	2 799.84	-439.63
Iron (Fe)	mg	12.66	12.73	0.07
Sodium (Na)	mg	424.32	321.73	-102.58
Magnesium (Mg)	mg	622.82	1 064.09	441.27
Calcium (Ca)	mg	1 383.25	723.21	-660.04
Phosphorous (P)	mg	645.68	794.60	148.92
Vit A	mg	1.61	1.13	-0.48
Vit B2 (Riboflavin)	µg	3.93	2.20	-1.73
Vit B12	µg	385.02	1 381.29	996.27
Vit B9 (Folate)	µg	2.68	379.46	376.77
Vit E	µg	8.99	15.63	6.64
Zinc	mg	10.53	9.06	-1.47
- Histidine	mg	1 678.77	1 659.90	-18.86
- Leucine	mg	4 886.96	6 446.57	1 559.61
- Lysine	mg	3 512.51	4 972.00	1 459.49
- Threonine	mg	2 343.99	2 557.22	213.23
- Tryptophan	mg	751.15	735.83	-15.32
- Met + cys	mg	2 348.22	2 416.50	68.28
- Methionine	mg	1 364.83	2 416.50	1 051.66

S7: Percentage of raw material in final product, based on market investigations in Gauteng

Product	Number of brands used	Average percentage raw material
1) Oat beverage	8.00	11.21%
2) Soy beverage	4.00	6.75%
3) Almond beverage	9.00	2.40%
4) Bovine milk	10.00	100.00%

* information was gathered from labelling or website information provided by the different anonymous brands in Gauteng

S8: Nutrient contribution ratios per food group (adjusted to content in final product)

Nutrient	Milk	Oats	Adj	Soybean	Adj	Nuts	Adj
Energy	0.0669	0.0027	0.0003	0.0041	0.0003	0.0058	0.0001
Carbohydrates	0.0378	0.0034	0.0004	0.0022	0.0001	0.0017	0.0001
Fibre	0.0000	0.0072	0.0008	0.0082	0.0006	0.0080	0.0002
Protein	0.1654	0.0041	0.0005	0.0116	0.0008	0.0066	0.0003
Fat	0.1288	0.0017	0.0002	0.0069	0.0005	0.0184	0.0002
Potassium (K)	0.1183	0.0021	0.0002	0.0120	0.0008	0.0050	0.0003
Iron (Fe)	0.0107	0.0060	0.0007	0.0224	0.0015	0.0082	0.0005
Magnesium (Mg)	0.1144	0.0089	0.0010	0.0174	0.0012	0.0155	0.0004
Calcium (Ca)	0.3192	0.0009	0.0001	0.0073	0.0005	0.0029	0.0002
Phosphorous (P)	0.4409	0.0151	0.0017	0.0254	0.0017	0.0193	0.0006
Vit A	0.1076	0.0000	0.0000	0.0002	0.0000	0.0002	0.0000
Vit B2 (Riboflavin)	0.3335	0.0015	0.0002	0.0101	0.0007	0.0054	0.0002
Vit B12	0.2597	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Vit B9 (Folate)	0.0409	0.0029	0.0003	0.0303	0.0020	0.0039	0.0007
Vit E	0.0004	0.0000	0.0000	0.0009	0.0001	0.0160	0.0000
Zinc	0.0894	0.0061	0.0007	0.0090	0.0006	0.0081	0.0002
- Cystine	0.1297	0.0087	0.0010	0.0186	0.0013	0.0099	0.0004
- Histidine	0.3097	0.0074	0.0008	0.0245	0.0017	0.0114	0.0006
- Leucine	0.2854	0.0058	0.0007	0.0191	0.0013	0.0085	0.0005
- Lysine	0.2999	0.0039	0.0004	0.0203	0.0014	0.0058	0.0005
- Methionine	0.3658	0.0076	0.0008	0.0149	0.0010	0.0100	0.0004
- Threonine	0.3257	0.0057	0.0006	0.0264	0.0018	0.0098	0.0006
- Tryptophan	0.3848	0.0097	0.0011	0.0313	0.0021	0.0137	0.0008

Sources: Delta Model (SNI, 2022) based on standard settings for 2020, baseline scenario
Note: average raw material content is used, however, if a single product is measured with a known raw material percentage, this can be replaced.

S9.1: Environmental footprint of almond cultivation (Marvinney and Kendall, 2021)

Indicator	Unit	Value	Comment
Fuel	kg/ha	20 365.91	Diesel + gasoline
Propane gas	kg/ha	98.9871	
Electricity	kWh/ha	83 156.86	
Pesticide	kg/ha	4 167.77	Nursery + orchard
Fertiliser N	kg/ha	3 614.00	Nursery + orchard
Fertiliser P	kg/ha	4 142.56	Nursery + orchard
Fertiliser K	kg/ha	224.6913	Nursery + orchard
Total synthetic fertiliser	kg/ha	21 075.32	Nursery + orchard
Blue water (irrigation)	kL/ha	2 986 840	
Yield	t/ha	2.33	Lifetime average per year
Maximum yield	t/ha	2.742	Based on maximum achieved in the area per year (lifetime avg./year)
Average age at removal	years	21.533	
Additional material input	kg/ha	1 147.81	Planting + irrigation
Density	trees/ha	312.4028	(Sapling required: 170.81 kg/ha)
Co-product generated	kg/ha	3401.71	Biomass, tree loss, hulls etc. (lifetime total averaged per year)
Recycled into farm	kg/ha	1295.741	Soil mulch, etc. (lifetime total averaged per year)
Sold/repurposed	kg/ha	1709.11	Dairy feed, energy generation (lifetime averaged per year)
In-field burning	kg/ha	396.8569	(lifetime total averaged per year)

S9.2: Environmental footprint results of oat cultivation

Indicator	Unit	Value	Comment
Fuel	kg/ha	50.3	Transport to silo 3.6 L, 5.5 L
Electricity	kWh/ha		Only farm maintenance (security, housing) – not recorded
Fertiliser N	kg/ha	77.75	
Fertiliser P	kg/ha	18.85	
Fertiliser K	kg/ha	6.25	
Lime	kg/ha	425	
Fungicide	kg/ha	0.4	
Insecticide	kg/ha	0.41	
Herbicide	kg/ha	1	
Blue water (irrigation)	kL/ha	0	Winter wheat planted in winter rainfall area
Yield	t/ha	2.95	
Maximum yield	t/ha	3.3	
Co-product generated	t/ha	2625.5	Crop residues
Recycled into farm	t/ha	172.42	29.8% residues left – 1% burnt
Sold/repurposed	t/ha	1844.525	70.2% residues removed
In-field burning	t/ha	7.81	1% burnt

Source: De Kock et al. (2018); GrainSA (2022) – based on wheat grown in South Africa

S9.3: Environmental footprint of soybean cultivation

Indicator	Unit	Value	Comment
Fuel	kL/ha	189.2	
Electricity	kWh/ha	2091.68	Drying beans = 133.88
Fertiliser N	kg/ha	60	

Fertiliser P	kg/ha	7	
Fertiliser K	kg/ha	19	
Lime	kg/ha	5.7	Both before and after harvest
Pesticide	CO_2eq/ha	628.6	Input not provided, only carbon eq.
Blue water (irrigation)	kL/ha		Not under irrigation
Yield	t/ha	1.8	
Maximum yield	t/ha	2.38	
Co-product generated	t/ha	2.94	crop residues
Recycled into farm	t/ha	1.0584	36% residues remaining
Sold/repurposed	t/ha	1.65	56% residues collected or repurposed
In-field burning	t/ha	0.235	8% burnt

Source: Tongwane et al. (2016); Blignaut et al., (2019); Kuboń et al. (2021); Pannar (2006)

S9.4: Environmental footprint results of dairy production

Indicator	Unit	Value
Farm size	ha	310
Herd	nr	1 188
Of which dairy	nr	588
Milk production	l/year	5 730 000
Per cow per year	l/year	9 744.897959
Feed produced	ton/year	12 960
Feed purchased	ton/year	3 360
N fertiliser	kg/ha	68
P fertiliser	kg/ha	0
Electricity	kwH/year	335 000
Fuel use	L/year	128 600
Milk production	l/year	6 546 500
Water	l/l	0.046
Electricity	kwH/L	0.056

Source: Owusu-Sekeyre et al. (2016); De Lima et al. (2022)

S10.1 : Nutrient score outline

Nutrient score						
Milk (milk type selected by user)		Content	Population nutrient req.	Supplement coefficient	Contribution coefficient	Nutrient content sufficiency
Nutrient	Unit	100ml	PNR (/day)	Sc	Cc	NSs
Energy	kJ		10 494.300	1.000	1.067	
Carbohydrates*	g		354.418	1.000	1.038	
Fibre	g		28.511	1.079	1.000	
Protein*	g		108.085	1.402	1.165	
Fat (count if type unknown)	g		75.436	1.000	1.129	
- PUFA*	g		15.310	1.000	1.000	

- MUFA*	g		26.445	1.000	1.000	
- Omega 3 (alpha l)	g		1.285	1.000	1.000	
- Omega 6 (lin)	g		12.991	1.000	1.000	
- Sat. fat*	g		24.774	1.000	1.000	
- Trans fat	g		1.682	1.000	1.000	
Potassium (K)	mg		2 799.838	1.000	1.118	
Iron (Fe)	mg		12.735	1.330	1.011	
Magnesium (Mg)	mg		321.733	1.000	1.114	
Calcium (Ca)	mg		1 064.088	1.415	1.319	
Phosphorous (P)	mg		723.207	1.000	1.441	
Vit A	mg		794.602	1.330	1.108	
Vit B2 (Riboflavin)	mg		1.131	1.000	1.333	
Vit B12	mg		2.195	1.000	1.260	
Vit B9 (Folate)	mg		379.459	1.721	1.041	
Vit D	mg		15.633	1.993	1.000	
Vit E	mg		13.922	1.425	1.000	
Zinc	mg		9.061	1.330	1.089	
Iodine	mg		157.962	1.000	1.000	
Amino acids						
- Histidine	mg		1 659.902	0.989	1.310	
- Leucine	mg		6 446.566	1.242	1.285	
- Lysine	mg		4 972.003	1.294	1.300	
- Methionine (+cystine)	mg		2 416.498	1.028	2.495	
- Threonine	mg		2 557.216	1.083	1.326	
- Tryptophan	mg		735.833	0.979	1.385	
- Isoleucine	mg		3 247.257	1.000	1.000	
- Phenylalanine (+tyr)	mg		4 220.116	1.000	1.000	
- Valine	mg		4 250.946	1.000	1.000	
1: Nutrient sufficiency score total						
Amino acids	Unit	AA %				IAA
- Histidine	mg/g					
- Leucine	mg/g					
- Lysine	mg/g					
- Methionine (+cystine)	mg/g					
- Threonine	mg/g					
- Tryptophan	mg/g					

- Isoleucine	mg/g					
- Phenylalanine (+tyr)	mg/g					
- Valine	mg/g					
1.1: Protein completeness factor		IAA (summed)			(pc)	
Health factors	Coefficient		PNR (/day)			Sub-factors
Added sugar (only added)	g					
Natural sugar	g					
Sodium (Na)	mg		1 381.292			
Exclusion threshold	Etc					
Healthy diet contribution	HDCc					
Nutrient score					NS	

Meaning	Color
User input	
Variable based on milk type	
Automatic calculated value	
Automatic calculated score	

S10.2A: Environmental score outline (green:user input; orange: calculated value; blue: subscore calculated value)

Paramater	Unit	Usage	Unit/ton
Total land	Ha		
Yield	Kl /ha		
By-product yield	Ton/ha		
Of which recycled into farm	Ton/ha		
Of which yielding a product or electricity	Ton/ha		
Production potential	Ton/ha		
Potential lost	Ton/ha		
Land use	Ha/ton		
Net yield (yield-by-product) per ha	Ton/ha		
Net land use	Ha/ton		
Farm productivity score			
Total synthetic fertiliser	Ton/ha		
N fertiliser	Ton/ha		
P fertiliser	Ton/ha		
K fertiliser	Ton/ha		
Lime	Ton/ha		
Pesticides (if type not known)	Ton/ha		

Herbicides	Ton/ha		
Insecticides	Ton/ha		
Fungicides	Ton/ha		
Fuel (inc. Material transport)	Kl/ha		
Electricity	Kwh/ha		
Blue water	kL/ha		
Farm input & footprint score			
Management & environmental indicators (see Appendix 6.4.2.B for input options)			
Cropping type			
Livestock use			
Soil type			
Soil test frequency			
Water test frequency			
Formal sustainability assessment (f)			
Crop health and/or livestock welfare assessment (f)			
Environmental score outline continued			
Sustainability training or education (f)			
Improvement in efficiency yearly			
Reduction of inputs yearly			
Management score			
1) farm environmental score			
Total litres produced at factory	Kl		
Of which product in question	Kl		
By-product yield	L/l		
Of which recycled into processing	L		
Of which a product or electricity	L		
Fuel (excluding distribution)	L/l		
Fuel (distribution)	L/l		
Electricity	Wh/l		
Blue water	L/l		
Are product specific inputs accurately measured in the factory?			
Total litres of final product at factory	L/year		
By-product yield	Kg/year		
Of which repurposed	Kg/year		
Of which a product or electricity	Kg/year		
Packaging used	Kg/year		

Fuel (excluding distribution)	L/year		
Fuel (distribution)	L/year		
Electricity	Kw/l/year		
Blue water	L/year		
Factory input & footprint score			
Management & environmental indicators (see			
Formal sustainability assessment (f)			
Sustainability training or education (f)			
Improvement in efficiency yearly			
Reduction of inputs yearly			
Management score			
2) factory environmental management score			
Environmental score		ES	

S10.2.B: Qualitative indicators question and user input options

Question/qualitative indicator	Options
Cropping type	Mono-cropping Rotational-cropping Inter-cropping Cover-cropping Regenerative cropping Agroforestry
Livestock use	None (if crops only without integration of livestock) TMR (no fodder carry) Post-harvest grazing (not for milking) TMR with Fodder carry Pasture based (single crops; with or without supplements)) Pasture based (mixed veld, with or without supplements)
Soil type	Sandy Clay Loam Silt Peat
Soil test frequency Water test frequency Formal sustainability assessment (f) Crop health and/or livestock welfare assessment (f) Sustainability training or education (f)	Never 5-10 years 2-5 years Yearly Twice or more per year
Improvement in efficiency yearly Reduction of inputs yearly	None 1-2% 2-5% 5-10% More than 10%

S10.3: Economic score outline (green: user input; orange: calculated value; blue: subscore)

Paramater	Unit/Factor	
Consumer cost		
Affordability		
COST	R/100ml	
FPL	pf1	

LBLP	pf2	
UBPL	pf3	
DBPL	pf4	
Price for reference poverty level:	Poverty Level	
Producer economic indicators		
Raw material producer		
Gross profit (whole farm)	R/year	
Wages (whole farm)	R/year	
Taxes (whole farm)	R/year	
Subsidies (whole farm)	R/year	
RM: GDP (agriculture) contribution		
Total expenses	R/year	
Income gained from repurposing waste	R/year	
Total production	kg/year	
Holistic cost of production	R/kg	
Holistic income from production	R/kg	
RM: Cost/Income Ratio		
Employees on farm	Nr employees	
Production potential	ton/year	
Potential lost	ton/ton	
Raw material producer economic score		
Final product producer		
Gross profit (whole factory)	R/year	
Wages (whole factory)	R/year	
Taxes (whole factory)	R/year	
Subsidies (whole factory)	R/year	
Processor: GDP (agriculture) contribution		
Economic score outline continued		
Total expenses	R/year	
Income gained from repurposing waste	R/year	
Total production	kg/year	
Holistic cost of production	R/kg	
Holistic income from production	R/kg	
Processor: Cost/Income Ratio		
Employees on factory	Nr employees	
Production potential	ton/year	
Potential lost	ton/ton	

Processing producer economic score		
Economic score	ES	

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