

## Article

# Climate-Smart Holistic Management System Criteria's Effectiveness on Milk Production in Lithuania

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**Abstract:** One of the problematic sectors according to GHG (greenhouse gas) and ammonia (NH<sub>3</sub>) emission quantities is agriculture. Without endangering food production (and intensifying), GHG emissions come from all sources in animal husbandry. The aim of this study was to comprehensively reduce GHG emissions by applying a holistic process management model to one of the most popular cowsheds in Lithuania (260-seat boxing cowshed, cows are milked on site, computerized management of technological processes, productivity of 8600 kg of milk, barn system, and liquid manure). Considering the cow keeping technology applied on the farm, the equipment used, and the feed production and ration system, a model for the management of technological parameters of production processes was prepared for the farm. This model balanced trade-offs among animal welfare, cow productivity, production costs, and GHG and NH<sub>3</sub> emissions. The aim of the research was the adaptation of the integrated model to fully control, manage, and optimize milk production processes through bio- and engineering innovations to implement climate-friendly feed production and feeding and feed rationing systems, to improve animal housing and working conditions, and to reduce GHG and NH<sub>3</sub> emissions without increasing production costs. The environmental impact assessment was performed with SimaPro 9.1 process modeling software. Data from milk production, biomass cultivation, and feed preparation, transportation, and equipment were used from the Ecoinvent v3 database. Based on the LML-I calculation methodology, the effect of processes was determined. To quantify the potential emissions in the dairy farm, the emission factors were estimated using a life cycle assessment method per functional unit—1000 kg—of standardized milk. Grass silage, maize silage, and feed concentrate were found to account for the largest share of gas emissions—26.09% (107.39 kg CO<sub>2</sub> eq. FU<sup>−1</sup>), 22.70% (93.44 kg CO<sub>2</sub> eq. FU<sup>−1</sup>), and 21.85% (89.92 kg CO<sub>2</sub> eq. FU<sup>−1</sup>) of the total CO<sub>2</sub> emissions during the process, respectively. Considering the critical points of the classic SC scenario, the cultivation technology was adjusted, where 50% of N fertilizers were replaced by bioproducts (biological preparations). Both scenarios—classic SC (control variant) and Bio SC (variants using bioproducts)—were evaluated for comparison. The use of biopreparations in the categories reduced the environmental impact from 0.1% to 45.7% in dairy production technology grass silage, barley grain, hay production, and corn silage stocks. The carbon footprint of the sustainable bio-based milk production (0.393 kg CO<sub>2</sub> eq. kg<sup>−1</sup> FPCM (fat- and protein-adjusted milk)) was lower by 4.6% compared to the average Lithuanian classic dairy farm (0.412 kg CO<sub>2</sub> eq. kg<sup>−1</sup> FPCM). Based on this methodology, it is possible to assess many dairy farms and address critical points in an integrated way, which can help to improve the quality of dairy production and the environment.

**Keywords:** global warming potential; greenhouse gas; holistic management; GHG reduction; milk production; fat- and protein-adjusted milk



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## 1. Introduction

In Lithuania, 20.4 million tons of greenhouse gases (GHGs) are emitted into the atmosphere. Transport, energy, and agriculture account for the largest share of GHG

emissions [1]. One of the main sectors in Lithuania in terms of GHG emissions is agriculture, which accounts for about 22.9% of total GHG emissions. These emissions include mainly carbon dioxide ( $\text{CO}_2$ ), which in Lithuania makes up 65.4% (of which 6% is from animal husbandry), methane ( $\text{CH}_4$ ) making up 16.8% (of which 8% is from animal husbandry), and nitrous oxide ( $\text{N}_2\text{O}$ ) making up 15.4% (of which 10% is from livestock) of total GHG emissions. Fluorinated gases, such as HFCs,  $\text{SF}_6$ , and  $\text{NF}_3$  together account for 2.4% of total GHG emissions in Lithuania. Due to agricultural activities, 45% of the GHGs (2071 kt  $\text{CO}_2$  eq.) are emitted from livestock farming (from total 4602 kt  $\text{CO}_2$  eq. emitted in 2019). The agricultural sector accounts the largest share of  $\text{N}_2\text{O}$ , accounting for about 85.1% of total  $\text{N}_2\text{O}$  and about 57.2% of total  $\text{CH}_4$  in Lithuania. GHG emissions from livestock production include  $\text{CH}_4$  from digestive processes accounting for 79% (1655 kt  $\text{CO}_2$  eq.),  $\text{CH}_4$  from manure management systems accounting for 14% (290 kt  $\text{CO}_2$  eq.), and  $\text{N}_2\text{O}$  from manure accounting for 7% (126 kt  $\text{CO}_2$  eq.) [2].

Agriculture emits a large volume of GHGs, which are produced during the digestive processes and from manure during storage and spreading in the fields. Ammonia ( $\text{NH}_3$ ) and nitrogen oxides ( $\text{NO}_x$ s) are indirect sources of  $\text{N}_2\text{O}$ .  $\text{NH}_3$  accounts for more than 90% of total  $\text{NH}_3$  in global livestock farming. The main measures to reduce greenhouse gas emissions are the development of sustainable agricultural activities [3].

Among the sustainable farming practices described in the literature, we can cite different studies. Introducing *Brachiaria* grass in cows' diet is recommended as one of the strategies to reduce feed shortages, especially in drier agroecological zones, at 23% during rainy seasons and 11% during dry periods. The positive effects of *Brachiaria* correspond to the role of agricultural technology in improving the productivity, income, and well-being of smallholder farmers [4].

The emergence of climate-smart agriculture in landscapes has been found to characterize climate-friendly practices on the field and farm scale, and the diversity of the landscape allows one to ensure resilience and to manage land-use interactions at the landscape level to achieve social, economic, and ecological impacts. The large-scale implementation of climate-smart landscape initiatives requires the strengthening of the technical capacity, institutions, and policy support for multilateral stakeholder planning, governance, spatial investment, and multi-objective impact monitoring [5].

Agroforestry, catch crops, crop rotation, cover crops, traditional organic composting, and integrated crop and livestock production can be used as exemplary practices for a climate-smart approach in agriculture. It benefits human health, natural resource management, energy saving, and socio-environmental integrity. It is recommended to integrate traditional and modern agricultural practices in order to increase food productivity while addressing the effects of climate change. Farmers should be provided with adequate crop insurance in the event of climate-induced crop failure or natural disasters, including research to increase the identification and exploration of traditional agricultural knowledge, the development of specific policy frameworks, the replacement of inorganic fertilizers with organic compost, the promotion of biofuels, and cooperation and coordination between citizens, policy makers, researchers [6].

The low-input system (LI) (without N fertilizers, without imported feed additive, and at 2.3 cows  $\text{ha}^{-1}$  livestock rate) was compared with the N-fertilized farm system (NF) (170 kg fertilizer N  $\text{ha}^{-1}$  per year, 3.0 cows  $\text{ha}^{-1}$ ) corresponding to the first level of intensification and with the N fertilization and maize silage supplementation system (NFMS) (170 kg fertilizer N  $\text{ha}^{-1}$  year, 13 t DM maize silage  $\text{ha}^{-1}$  year, 5.2 cows  $\text{ha}^{-1}$ ) to reflect the possible future intensification option [7].

A cost-benefit analysis of the public investment program to promote climate-friendly agriculture in Lesotho has been carried out in South Africa in order to transform the agricultural sector of small farms into more sustainable and cleaner production systems. Farmers and society as a whole have been found to benefit from investing in climate-friendly agriculture that reduces GHG emissions [8].

Climate-advanced agriculture (CSA) is an integrated approach that depends on national and international agencies, government, and civil society. Expansion and advisory services can fill the knowledge gap by providing clarity on the components of CSA and related issues, helping farmers to cope with the various impacts of climate change, and raising awareness through appropriate tools to communicate different adaptation and mitigation strategies. New expansion methods for a changing climate, such as information and communication technology (ICT)-based extension services and climate information services, have been found to help farmers at the grassroots level [9].

Socio-economic sustainability is paramount in low-income countries, where milk production and consumption are means of improving people's nutrition and health, as well as economic opportunities to raise the livelihoods of farmers. In this context, sustainable intensification (increasing milk production from currently available resources) is the single most important and practical strategy to improve the sustainability of milk production and consumption in low-income countries [10]. The improvement of the genetic potential of animals and the availability of high-quality feed with feed additives [11], and ensuring a proper balanced diet, which has a substantial effect on animal wellbeing, homeostasis, and inflammatory response, are important [12]. They are the most promising strategies for improving milk production and sustainability [10]. The importance of fast and reliable feed analysis was successfully proven to determine quickly and cost-effectively the different compositional and digestibility traits in hay-based total mixed rations. Provided formulation of diets containing a proper nutrient profile sustained physiological, metabolic, and immunological processes and maximized cows' diet utilization and conversion of the ingested feed [13]. EU rural development policy is addressing the challenges of climate change in agriculture through the introduction of public voluntary schemes that provide financial support for climate-friendly agricultural practices. The three schemes of the Veneto Rural Development Program include no-till, reduction in fertilizers, and reduction in water and fertilizers. It is necessary to take non-financial factors into account to create more effective schemes to encourage farmers to adopt and continue such practices in the long term [11]. The inclusion of hay-based feed in the ration positively affected milk organoleptic characteristics and cheese production quality [14].

The environmental footprint of Alpine dairy products (milk, cheese, and butter) showed that the impact on environment was mainly due to milk production and much less due to milk processing. Farm impact and efficiency differed per unit of milk and per unit of land. The lowest impact was observed at moderate milk yield, low livestock numbers, and low concentrates [15].

The UK Livestock Study used life cycle assessment (LCA) methods to model milk production based on two genetic advantages of Holstein Friesian cows managed in two new and two traditional UK dairy systems. LCA was used to quantify the effects of the distribution and management of feed components on the carbon footprint of dairy production. The GHG emissions of the systems were found to differ significantly in terms of total and source category emissions, and most management systems found a significant average difference in embedded emissions. The traces of the system considering the effects of changes in feed digestibility and crude protein also differed significantly from the traces of the system using standard methods [16]. According to Zucali et al., the environmental impact assessment of dairy goat milk production showed that the lower the individual milk production, the higher the environmental impact. Following their estimation, the carbon footprint was higher than in dairy production (climate change has resulted in an average of 2.67 kg CO<sub>2</sub> eq. kg<sup>-1</sup> fat- and protein-adjusted milk (FPCM) with high variability (min: 1.12 kg CO<sub>2</sub> eq. kg<sup>-1</sup> FPCM; max: 5.05 kg CO<sub>2</sub> eq. kg<sup>-1</sup> FPCM)). Purchased feed was a key point in several categories of environmental impacts (such as freshwater eutrophication, land use, and depletion of mineral, fossil, and renewable resources). Intestinal emissions and discharges from manure storage were points of climate change, particulate matter, and land acidification. The main factor influencing the six main exposure categories was individual milk production, which showed the importance of

livestock intensity and of limited land availability which can have a negative impact on environmental performance [17].

The impact of limping intervention on rubber mats in corridors on the global warming potential (GWP), terrestrial acidification (TAP), freshwater and marine eutrophication (FEP and MEP), and the use of non-renewable and renewable energy sources in Austrian production sites before and after the installation of rubber mats were assessed by Herzog et al. [18]. In both systems, the TAP, MEP, and MET estimates were found to be insensitive to changes in carpet durability due to the negligible emission impact associated with carpet production ( $\leq 0.05\%$ ). Given the effectiveness of soft flooring in reducing physical injury, the benefits of rubber mats in reducing emissions could be expected to be more pronounced in the case of foot ulcers than in digital dermatitis. The findings showed that measures to improve health and wellbeing could reduce dairy emissions or at least outweigh the environmental costs of implementing them [18].

The type of farming specializing in milk production has a more favorable environmental profile compared to the mixed animal species. Improving management practice and use of farm technologies undoubtedly improve efficiency and sustainability of the whole farm [19]. According to Bieńkowski et al., the group of processes responsible for direct emissions from cattle farming (enteric fermentation and manure management) has the greatest impact on climate change and acidification. Imported feed and domestic feed have contributed significantly to the depletion and eutrophication of abiotic fossil fuel resources. In the case of mixed livestock farming, the reduction in both the overall environmental impact and the cost should be key factors in improving the eco-efficiency of milk production [20].

The aim of this research was the adaptation of the integrated model to fully control, manage, and optimize milk production processes through bio- and engineering innovations, to implement climate-friendly feed production and feeding and feed rationing systems, to improve animal housing and working conditions, and to reduce GHG and  $\text{NH}_3$  emissions without increasing production costs.

## 2. Methods

The goal of this study was to identify and evaluate the environmental burdens associated with milk production in Lithuania through an LCA approach. One milk production sector was identified as the main hotspot in the production chain. An alternative was proposed (bio strategy) to mitigate the environmental impacts related to the entire system.

Depending on the cow keeping technology, the equipment used, and the feed production and rationing system on the farm, a model for the management of the technological parameters of the production processes was developed for each farm. This model found a trade-off between animal welfare, cow productivity, production costs, and GHG and  $\text{NH}_3$  emissions. A holistic process management model reduced greenhouse gas emissions without compromising other production indicators, and without increasing or decreasing  $\text{NH}_3$  emissions. The management model includes the following milk production processes:

- Fodder production (crop cereal production and pastures), silage production, fodder preparation and storage, preparation of climate-friendly rations, and feeding;
- Animal housing (barns), housing systems and methods, automation of technological processes, improvement of housing conditions, and herd management systems;
- Manure handling: removal from barns, storage, and incorporation into the soil.

In order to increase the competitiveness of farms, it was necessary to reduce air pollution, to increase operational efficiency (to increase productivity), and to pursue a rational investment policy, focusing more on farm equipment (which increased productivity) and looking for cheap and environmentally friendly technologies.

Air pollution was measured in terms of GHG and  $\text{NH}_3$  emissions. The main GHG emissions were carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), and nitrous oxide ( $\text{N}_2\text{O}$ ).

GHG emissions were reduced and the impact of livestock farming on climate change was mitigated through a conversion factor of all innovations in dairy production processes as needed:

- Optimizing animal housing conditions and increasing animal productivity;
- Optimizing feed production, the feeding system, and the feed ration (a new climate-friendly feed ration was applied);
- Reducing energy consumption for milk production;
- Controlling gas evaporation processes from manure: barn, manure storage, and fertilizing fields.

### 2.1. Object Characteristic

Modernization of cow housing technologies is intensively underway in Lithuania. Old cowsheds are being reconstructed or new boxing cowsheds are being built. The main direction of modernization of cowsheds is box barns with shallow boxes and manure handling technology. The aim of the research was to evaluate the direction of modernization of Lithuanian cowsheds. The most popular cow housing technology in Lithuania was chosen for the research. Cows are kept in the barn all year round. The most popular cowshed can be described as follows: about 200 cows are kept, the cowshed is semi-warm (roof-insulated and walls without thermal insulation), it has shallow rest boxes, the bed is not curved, manure is removed from the tracks by a scraper conveyor, and fodder is distributed by a mobile distributor). The technology of the most popular cowshed is best matched by the 260-seat box, located in Biržai district. Therefore, we selected this farm for detailed research.

In the Lithuanian Parovėja village, LT-41480, Biržai district, with 260-bed boxing cows, cows are milked on site, technological process control is computerized, and productivity averages 8600 kg of milk, barn system, and liquid manure.

The module included the use of energy and auxiliary materials for the operation of lighting, storage, and drying of roughage, slurry agitator, milking machine, milk cooling, cleaning, and drinking water. The functional unit was 1 livestock unit (LU) during 1 year. The original inventory is based on swiss center for life cycle inventories of agricultural production systems.

Manure is removed from the barn by self-contained channels, to which water (10–20 cm) must be added before the animals are introduced into the barn. The gutters are without slope, otherwise the urine would run off and the hard part would remain. When the bottom of the gutter falls through the grate, the manure and slurry mix in it and move constantly toward the collector under the influence of traction forces.

Liquid manure can be used to fertilize, in addition to those already mentioned, perennial grasses under manure, meadows and pastures, various cereal–legume mixtures, annual grasses, catch crops, etc. When fertilizing with manure, bell grasses can only be fully supplied with nutrients until the first harvest, when there is usually enough moisture in the soil. If the fields are watered, liquid manure can be applied throughout the summer. In soils where there is a risk of “clogging” (clay and shale), the single manure rate should not exceed 25 t ha<sup>−1</sup>, as manure film may form and regenerating plants may be damaged. Mown meadows are fertilized for the first 7 days after mowing. If the legume crop contains about 60%, the single nitrogen rate should not increase (25–30 t ha<sup>−1</sup> manure) per fertilization. Annual fodder plants are fertilized with a liquid manure–water solution. After fertilizing, the plants must be washed with clean water. Barley and oats grown for fodder should be fertilized at a rate of about 24–28 t ha<sup>−1</sup> manure. However, the nitrogen obtained from manure should be only 50–75% of the total amount needed by plants. The best fertilization time is before autumn plowing in heavy soils, and spring fertilization is more recommended in sandy or sandy soils. Pasture productivity increases especially when manure is applied several times. The one-off rate should not exceed 25–35 t ha<sup>−1</sup>. Animals prefer to eat grass in pastures where the plants have been “washed” with clean water after fertilization.

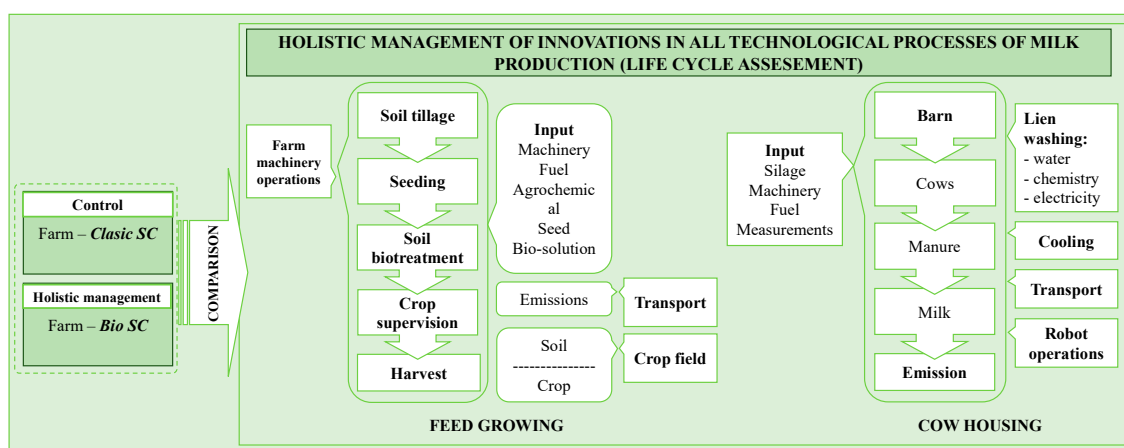


Most of the C meadows accumulate in the roots. However, we did not tie meadows in this work. This was not significantly affected, as it is meadows with short-term growth, not forests. The research barn where the cows live all year round and the grazing of the cows were excluded because the grass was introduced into the barn. Therefore, grazing was not included.

Included activities: the inventory considered the energy and auxiliary materials such as water, lubricating oil, and cleaning agents for the use of the described module for one year. Additionally included was the use of the infrastructure with the binding of a certain part of the appropriate infrastructure module.

## 2.2. GHG Evaluation from Automated Milk Production

Depending on the cow housing technology used in the farm, the equipment, and feed production and ration systems used, a model for the management of the technological parameters of the production processes was prepared for the farm. This model found a trade-off between animal welfare, cow productivity, production costs, and GHG and NH<sub>3</sub> emissions. A holistic process control model reduced GHG emissions without compromising other production parameters and reduced NH<sub>3</sub> emissions (Figure 1).



**Figure 1.** Holistic model of technological process management.

The holistic process management model includes the following dairy production processes such as feed production (crop-cereals, other crops, and pastures), silage production, feed preparation and storage, climate-friendly rations, feeding, animal housing (barns), housing systems and methods, automation of technological processes, improvement of storage conditions, herd management systems, and manure management: removal from barns, storage, and incorporation into the soil.

## 2.3. Functional Unit

The life cycle impact assessment's relative approach (CML-IA baseline V3.06/EU25) [21] is based on the functional unit (FU) (EN ISO 14040:2006) [22], which normalizes the evaluated data. The mass-based FU used in the LCA model was used to analyze the results based on the milk production and its related environmental effects.

The raw milk weight was converted to FPCM using equation, as suggested by IDF guidelines [23]:

$$FPCM = \text{raw milk production} (0.1226 \text{ fat} + 0.0776 \text{ true protein} + 0.2534) \quad (1)$$

After calculating the detailed life cycle assessment plan and rejecting equally methodical and influential milk production processes (dairy farm buildings), the functional unit was selected as 1000 kg of fat- and protein-corrected milk (FPCM) at farm gate.

#### 2.4. Evaluation of Impact Categories from Automated Milk Production

The environmental impact assessment was conducted using SimaPro 9.1 process modeling software (©PRé Sustainability B.V., Amersfoort, The Netherlands). The data on milk production, biomass cultivation, and feed preparation, transportation, and equipment were from Ecoinvent v3 database [24]. Based on the CML-I calculation methodology, we determined the resulting impact of processes. The impact categories, given in Table 1, were chosen for evaluation.

**Table 1.** The impact categories used for evaluation.

| Impact Category                  | Unit                                 |
|----------------------------------|--------------------------------------|
| Abiotic depletion                | kg Sb eq.                            |
| Abiotic depletion (fossil fuels) | MJ                                   |
| GWP (GWP100a)                    | kg CO <sub>2</sub> eq.               |
| Ozone layer depletion (ODP)      | kg CFC-11 eq.                        |
| Human toxicity                   | kg 1,4-DB eq.                        |
| Fresh water aquatic ecotoxicity  | kg 1,4-DB eq.                        |
| Marine aquatic ecotoxicity       | kg 1,4-DB eq.                        |
| Terrestrial ecotoxicity          | kg 1,4-DB eq.                        |
| Photochemical oxidation          | kg C <sub>2</sub> H <sub>4</sub> eq. |
| TAP                              | kg SO <sub>2</sub> eq.               |
| FEP                              | kg PO <sub>4</sub> eq.               |

Depending on the cow keeping technology applied on the farm, the equipment, and feed production and ration system used, a model for the management of technological parameters of production processes was prepared for each farm type (scenarios).

This model found a trade-off between animal welfare, cow productivity, production costs, and GWP and NH<sub>3</sub> emissions. A holistic process control model reduced GHG emissions without compromising other production parameters and reduced NH<sub>3</sub> emissions.

The holistic process management model includes the following milk production processes:

- Fodder production (crop-growing of other cereals and pastures), production of silage, preparation and storage of fodder, preparation of climate-friendly rations, and feeding;
- Animal housing (barns) systems and methods, automation of technological processes, improvement of housing conditions, and herd management systems;
- Manure handling: removal from barns, storage, and incorporation into the soil.

The model of holistic dairy farm was based on the assumption that the farm contains 240 milking cows per year. Each cow produces 6225 kg of raw milk (the average annual fat content is 4.16% and the protein content is 3.25%).

Cow productivity is 6225 kg of milk per year per cow (average LT productivity in 2019). The cow is milked an average of 305 days a year and weaned 60 days before calving. An average of 60 cows are culled each year and sold for meat. They are replaced by young and healthy cows. The functional unit taken in this study was expressed in milk, and as a result, the study was performed within certain limits and only those cows that produce milk were considered. For calves, no assessment was provided.

The average daily water consumption per cow is 100 L (80 L to drink). One cow needs 36,500 L of water in a year. The water must have drinking water quality. Corn silage is produced in a trench. Grass silage is produced in a roll. The feed mixture is prepared in a stationary trolley and the feed is distributed by a robot. Amount of feed per cow is hay—440 kg year<sup>−1</sup>, grass silage—5250 kg year<sup>−1</sup>, corn silage—5230 kg year<sup>−1</sup>, green fodder grass—8990 kg year<sup>−1</sup>, and concentrated feed—1350 kg year<sup>−1</sup>.

### 2.5. Holistic Management Effect for GHG Reduction

GHG emissions can be reduced and the impact of livestock farming on climate change can be mitigated through integrated management of all milk production technological processes and the following activities:

- Improving housing conditions and increasing cow productivity;
- Optimizing feed production and the feeding system;
- Applying a climate-friendly feed ration;
- Reducing energy consumption for milk production;
- Controlling gas evaporation processes from manure: in the barn, manure storage, and fertilizing the fields;
- Reducing  $\text{NH}_3$  emissions and the use of inorganic N fertilizers.

It can be the effective management of technological processes, introduction of a new climate-friendly diet for cows with improved digestibility of nutrients, reduction in methane emissions from digestive processes, and optimization of the technological processes of manure handling.

### 2.6. Statistical Analysis

Statistical analysis was performed using the Tukey's HSD test, estimating the essential difference margin HSD05 at the 95% probability level to ensure that the differences in the means of the data are significant. In the figures, the letters indicate significant differences between the factors. The same letter indicates that there was no significant difference.

## 3. Results and Discussion

A new model of technological process management was evaluated, which included complex innovation management in all technological processes of milk production. The unique management model solution is to reduce GHG and  $\text{NH}_3$  emissions through innovative environmentally friendly technologies, improved animal housing, improved human working conditions, and no increase in production costs. The model covers the following milk production processes, such as cow housing (improving animal housing conditions and increasing cow productivity), feed rationing, feed production (climate-friendly feed ration, optimized feed production, and reduced use of fuel and inorganic N fertilizers), increased energy use efficiency (reducing energy consumption), manure management in the barn, manure storage, and fertilizing the fields (optimizing parameters and reducing GHG and  $\text{NH}_3$  evaporation from manure).

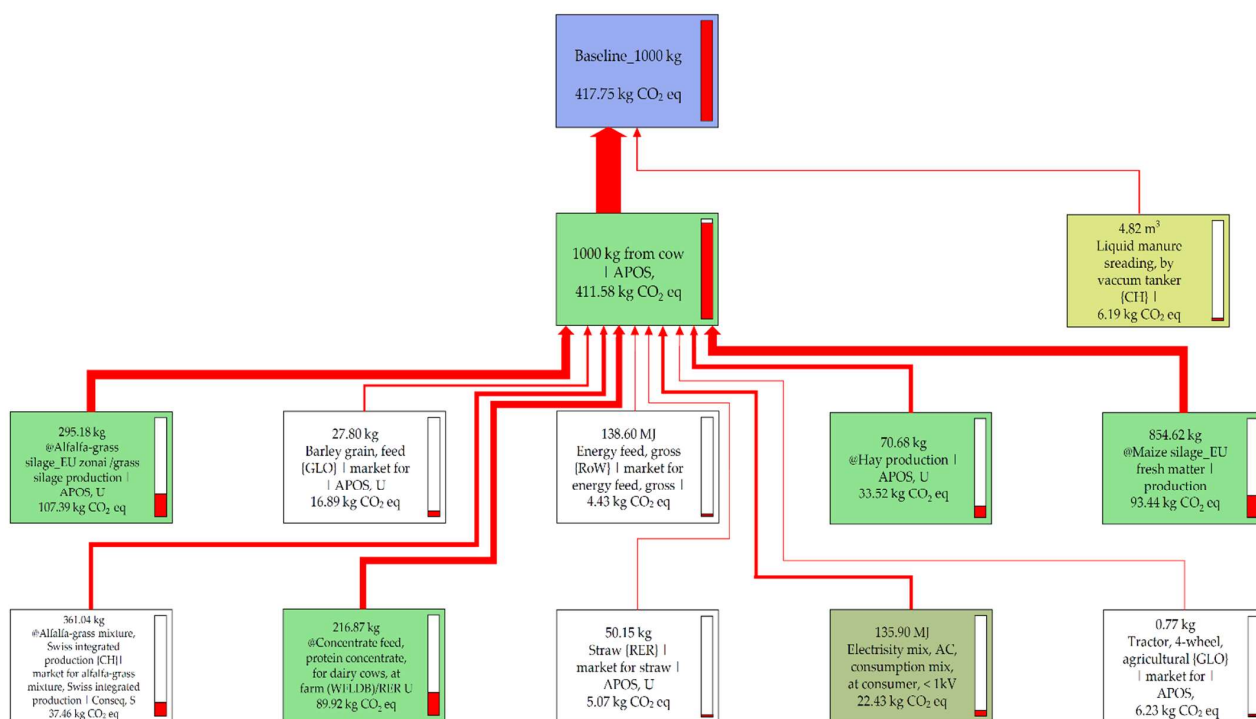
The emission factors were assessed using an LCA method and were used to create a classic scenario (Classic SC) process diagram which is distinguished (Figure 2). Based on the results of the processes, the critical points were visible at the parts of the processes with the highest potential for emissions. Grass silage, maize silage, and concentrate feed were found to account for the largest share of gas emissions, accounting for 26.09% ( $107.39 \text{ kg CO}_2 \text{ eq. FU}^{-1}$ ), 22.70% ( $93.44 \text{ kg CO}_2 \text{ eq. FU}^{-1}$ ), and 21.85% ( $89.92 \text{ kg CO}_2 \text{ eq. FU}^{-1}$ ), respectively, of all  $\text{CO}_2$  emissions from the process.

Emissions to the environment from other categories of milk production processes, calculated using LCA and presented in Table 2, were also visible.

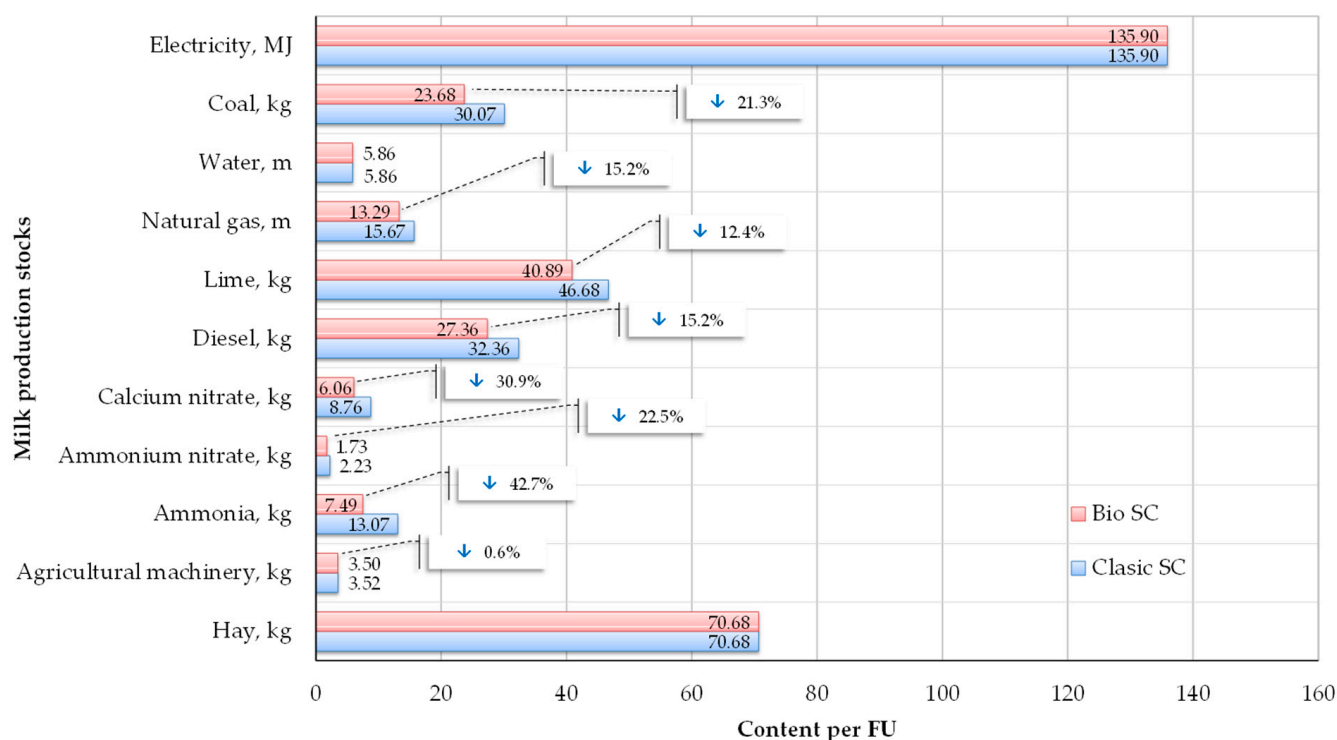
The environmental impact assessment showed that the other environmental categories in LCA also had the highest environmental impact—grass silage, maize silage, and concentrate in the feed stock. The additives in these parts, such as protein additives in corn and rapeseed, etc., are used in the feed technology for feed preparation. These crops are grown using N fertilizers, which have a significant impact on the environment. Thus, examining the critical points in the Classic SC scenario (marked in red in Figure 2 and Table 2), the cultivation technology was adjusted to replace 50% of N fertilizers to bio products.

For comparison, both scenarios (Classic SC and Bio SC) were further evaluated and preliminary results for the main stocks (Figure 3) and results in the exposure categories (Table 3) are presented.





**Figure 2.** Results of the GHG potential (kg CO<sub>2</sub> eq. FU<sup>-1</sup>) of the Classic SC processes. Critical points of the process are identified by a red bold line.



**Figure 3.** Data on basic stocks of milk production per FU.

**Table 2.** Results of Classic SC management and milk production (for 1 FU = 1000 kg of milk).

| Impact Category                                       | Abiotic Depletion      | Abiotic Depletion     | GWP                      | Ozone Layer Depletion  | Human Toxicity        | Fresh Water Aquatic Ecotox. | Marine Aquatic Ecotoxicity | Terrestrial Ecotoxicity | Photochemical Oxidation                | TAP                       | FEP                       |
|-------------------------------------------------------|------------------------|-----------------------|--------------------------|------------------------|-----------------------|-----------------------------|----------------------------|-------------------------|----------------------------------------|---------------------------|---------------------------|
| No Unit                                               | 1 kg Sb eq.            | 2 MJ                  | 3 kg CO <sub>2</sub> eq. | 4 kg CFC-11 eq.        | 5 kg 1,4-DB eq.       | 6 kg 1,4-DB eq.             | 7 kg 1,4-DB eq.            | 8 kg 1,4-DB eq.         | 9 kg C <sub>2</sub> H <sub>4</sub> eq. | 10 kg SO <sub>2</sub> eq. | 11 kg PO <sub>4</sub> eq. |
| Total                                                 | 0.012                  | 2771.2                | 411.58                   | $3.14 \times 10^{-5}$  | 199.34                | 209.24                      | 236,503                    | 20.70                   | 0.064                                  | 5.34                      | 4.97                      |
| Cow milk production from cow                          | 0                      | 0                     | 0.098                    | 0                      | $5.83 \times 10^{-5}$ | 0                           | 0                          | 0                       | $1.72 \times 10^{-5}$                  | $9.33 \times 10^{-4}$     | $2.62 \times 10^{-4}$     |
| Grass silage                                          | $4.76 \times 10^{-3}$  | 512.73                | 107.40                   | $5.18 \times 10^{-6}$  | 41.42                 | 33.64                       | 44,018                     | 4.40                    | 0.011                                  | 0.898                     | 2.07                      |
| Barley grain, feed                                    | $6.34 \times 10^{-4}$  | 128.77                | 16.78                    | $1.32 \times 10^{-6}$  | 14.87                 | 13.39                       | 14,452                     | 2.05                    | 0.003                                  | 0.140                     | 0.153                     |
| Energy feed, gross                                    | $8.55 \times 10^{-5}$  | 18.7                  | 3.00                     | $1.94 \times 10^{-7}$  | 1.67                  | 2.66                        | 1813                       | 0.247                   | 0.001                                  | 0.022                     | 0.014                     |
| Hay production                                        | $1.12 \times 10^{-3}$  | 219.45                | 33.52                    | $1.53 \times 10^{-6}$  | 29.72                 | 26.17                       | 37,370                     | 0.777                   | 0.005                                  | 0.254                     | 0.511                     |
| Limestone, crushed, washed                            | $2.98 \times 10^{-7}$  | 0.200                 | 0.014                    | $2.46 \times 10^{-9}$  | 0.007                 | $3.36 \times 10^{-3}$       | 6.15                       | $4.63 \times 10^{-5}$   | $2.80 \times 10^{-6}$                  | $1.37 \times 10^{-4}$     | $3.38 \times 10^{-5}$     |
| Magnesium oxide                                       | $6.02 \times 10^{-7}$  | 1.04                  | 0.428                    | $6.96 \times 10^{-9}$  | 0.064                 | 0.210                       | 201.38                     | $8.39 \times 10^{-4}$   | $7.39 \times 10^{-5}$                  | $8.14 \times 10^{-4}$     | $2.41 \times 10^{-4}$     |
| Maize silage                                          | $3.16 \times 10^{-3}$  | 549.78                | 93.45                    | $5.68 \times 10^{-6}$  | 33.75                 | 65.03                       | 43,824                     | 2.44                    | 0.012                                  | 1.60                      | 1.04                      |
| Grass mixture                                         | $1.17 \times 10^{-3}$  | 299.70                | 37.46                    | $2.96 \times 10^{-6}$  | 36.48                 | 16.27                       | 32,066                     | −1.41                   | 0.007                                  | 0.928                     | 0.339                     |
| Concentrate feed, protein concentrate, for dairy cows | $3.99 \times 10^{-4}$  | 747.37                | 89.92                    | $8.23 \times 10^{-6}$  | 33.76                 | 37.79                       | 45,236                     | 7.59                    | 0.016                                  | 1.27                      | 0.788                     |
| Selenium                                              | $1.54 \times 10^{-11}$ | $4.59 \times 10^{-7}$ | $3.27 \times 10^{-8}$    | $7.30 \times 10^{-15}$ | $6.55 \times 10^{-8}$ | $4.14 \times 10^{-8}$       | $7.94 \times 10^{-5}$      | $1.13 \times 10^{-10}$  | $4.03 \times 10^{-11}$                 | $1.01 \times 10^{-9}$     | $8.00 \times 10^{-11}$    |
| Sodium chloride, powder                               | $5.35 \times 10^{-9}$  | $7.04 \times 10^{-4}$ | $6.63 \times 10^{-5}$    | $4.85 \times 10^{-12}$ | $1.90 \times 10^{-4}$ | $1.13 \times 10^{-4}$       | 1.86                       | $2.49 \times 10^{-7}$   | $1.80 \times 10^{-8}$                  | $4.10 \times 10^{-7}$     | $1.73 \times 10^{-7}$     |
| Straw                                                 | $1.92 \times 10^{-4}$  | 44.71                 | 5.05                     | $4.96 \times 10^{-7}$  | 4.66                  | 12.42                       | 3745                       | 4.57                    | 0.001                                  | 0.048                     | 0.051                     |
| Transport                                             | $4.78 \times 10^{-7}$  | 0.079                 | 0.006                    | $8.92 \times 10^{-10}$ | 0.007                 | 0.005                       | 5.47                       | $1.10 \times 10^{-5}$   | $1.44 \times 10^{-6}$                  | $1.76 \times 10^{-5}$     | $5.15 \times 10^{-6}$     |
| Tap water                                             | $6.04 \times 10^{-5}$  | 21.80                 | 2.02                     | $2.21 \times 10^{-7}$  | 1.53                  | 1.62                        | 3497                       | 0.024                   | 0.001                                  | 0.010                     | 0.006                     |
| Diesel, burned in agricultural machinery              | $2.32 \times 10^{-7}$  | 0.047                 | 0.004                    | $5.12 \times 10^{-10}$ | 0.003                 | 0.002                       | 3.31                       | $1.34 \times 10^{-5}$   | $9.92 \times 10^{-7}$                  | $2.40 \times 10^{-5}$     | $6.86 \times 10^{-6}$     |
| Electricity mix                                       | $5.73 \times 10^{-7}$  | 226.79                | 22.43                    | $5.58 \times 10^{-6}$  | 1.40                  | 0.044                       | 10,264                     | 0.018                   | 0.008                                  | 0.165                     | 0.005                     |

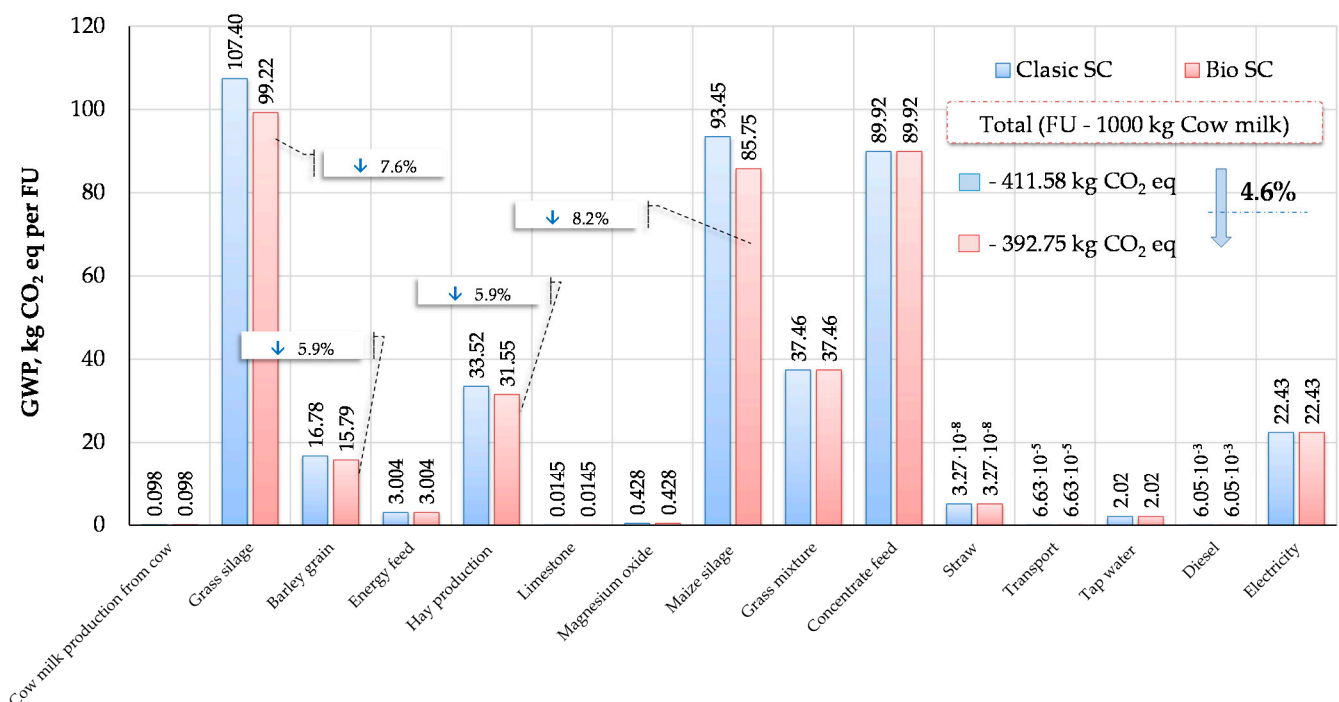
**Table 3.** Results of holistic cow management and milk production (for FU = 1000 kg of milk).

| No | Impact Category                  | Unit                                 | Classic SC            | Bio SC                | Bio SC Difference from Classic SC, % |
|----|----------------------------------|--------------------------------------|-----------------------|-----------------------|--------------------------------------|
| 1  | Abiotic depletion                | kg Sb eq.                            | 0.012                 | 0.011                 | ↓ 7.0                                |
| 2  | Abiotic depletion (fossil fuels) | MJ                                   | 2771.2                | 2588.4                | ↓ 6.6                                |
| 3  | GWP                              | kg CO <sub>2</sub> eq.               | 411.58                | 392.75                | ↓ 4.6                                |
| 4  | Ozone layer depletion            | kg CFC-11 eq.                        | $3.14 \times 10^{-5}$ | $2.97 \times 10^{-5}$ | ↓ 5.3                                |
| 5  | Human toxicity                   | kg 1,4-DB eq.                        | 199.34                | 183.18                | ↓ 8.1                                |
| 6  | Fresh water aquatic ecotoxicity  | kg 1,4-DB eq.                        | 209.24                | 195.78                | ↓ 6.4                                |
| 7  | Marine aquatic ecotoxicity       | kg 1,4-DB eq.                        | 236,503               | 221,117               | ↓ 6.5                                |
| 8  | Terrestrial ecotoxicity          | kg 1,4-DB eq.                        | 20.70                 | 18.83                 | ↓ 9.0                                |
| 9  | Photochemical oxidation          | kg C <sub>2</sub> H <sub>4</sub> eq. | 0.064                 | 0.060                 | ↓ 5.3                                |
| 10 | TAP                              | kg SO <sub>2</sub> eq.               | 5.34                  | 4.29                  | ↓ 19.7                               |
| 11 | FEP                              | kg PO <sub>4</sub> eq.               | 4.97                  | 4.73                  | ↓ 4.8                                |

It was found that the introduction of biopreparations in the cultivation technology, replacing 50% of the N fertilizer, reduced the amount of stocks used per FU. In the Bio SC scenario, the amount of coal per FU decreased to 21.3% (23.68 kg FU<sup>−1</sup>), natural gas—up to 15.2% (13.29 m<sup>3</sup> FU<sup>−1</sup>), lime—up to 12.4% (40.89 kg FU<sup>−1</sup>), diesel—up to 15.5 % (27.36 kg FU<sup>−1</sup>), calcium nitrate—up to 30.9% (6.06 kg FU<sup>−1</sup>), ammonium nitrate—up to 22.5% (1.73 kg FU<sup>−1</sup>), NH<sub>3</sub>—up to 42.7% (7.49 kg FU<sup>−1</sup>), and agricultural machinery—up to 0.6% (3.50 kg FU<sup>−1</sup>) (Figure 3). Stocks of hay (70.68 kg), water (5.86 m<sup>3</sup>), and electricity (135.90 MJ) remained unchanged.

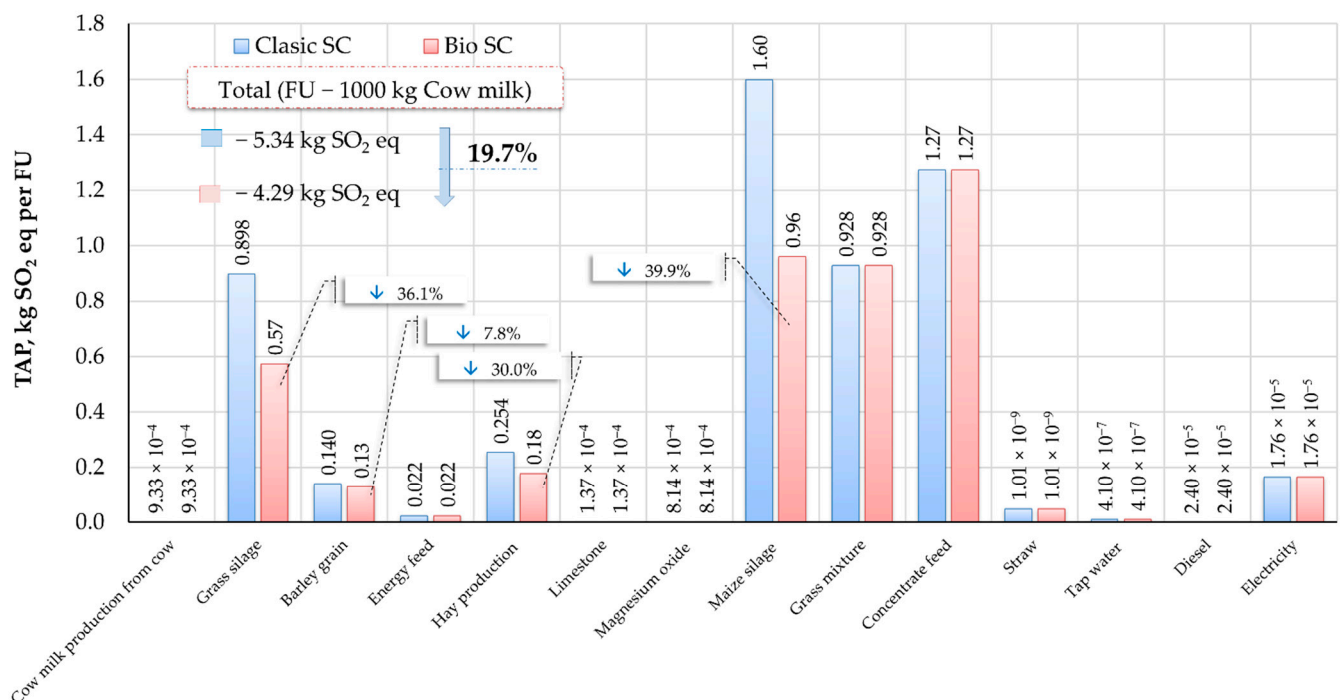
The data in Table 3 show that the potential environmental impact of cow management and milk production decreased from 4.6 to 19.7% in all exposure categories.

Figure 4 shows the environmental impact of milk production stocks in both scenarios (CO<sub>2</sub> emissions (kg CO<sub>2</sub> eq. FU<sup>−1</sup>)), where bio-preparations were projected to replace 50% of N fertilizers. The data showed that the largest share of CO<sub>2</sub> emissions determined in the stock was grass silage (Classic SC—107.4 kg CO<sub>2</sub> eq. FU<sup>−1</sup>), which accounted for 26.09% of the total CO<sub>2</sub> emissions from milk production stocks. The application of biopreparations reduced this share to 7.6% (Bio SC—99.22 kg CO<sub>2</sub> eq. FU<sup>−1</sup>).

**Figure 4.** GWP of milk production stocks per FU.

The use of biopreparations reduced the GWP of milk production stocks in barley grain, hay production, and maize silage stocks, respectively, to 5.9% (Classic SC—16.79 kg CO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—15.79 kg CO<sub>2</sub> eq. FU<sup>-1</sup>), 5.9% (Classic SC—33.52 kg CO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—31.55 kg CO<sub>2</sub> eq. FU<sup>-1</sup>), and 8.2% (Classic SC—93.45 kg CO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—85.75 kg CO<sub>2</sub> eq. FU<sup>-1</sup>). The total GWP of milk production stocks per FU decreased to 4.6% (Bio SC—392.75 kg CO<sub>2</sub> eq. FU<sup>-1</sup>).

We found a potential equivalent effect of acidification of FU stocks on milk production scenarios (Figure 5). The highest sulfur dioxide emission potential was recorded in the Classic SC maize silage stock (1.60 kg SO<sub>2</sub> eq. FU<sup>-1</sup>), which accounted for 29.96% of total SO<sub>2</sub> emissions from open sources. When converting fertilizers to biopreparations, the sulfur dioxide emission potential in this part was reduced to 39.9% (Bio CS—0.96 kg SO<sub>2</sub> eq. FU<sup>-1</sup>).

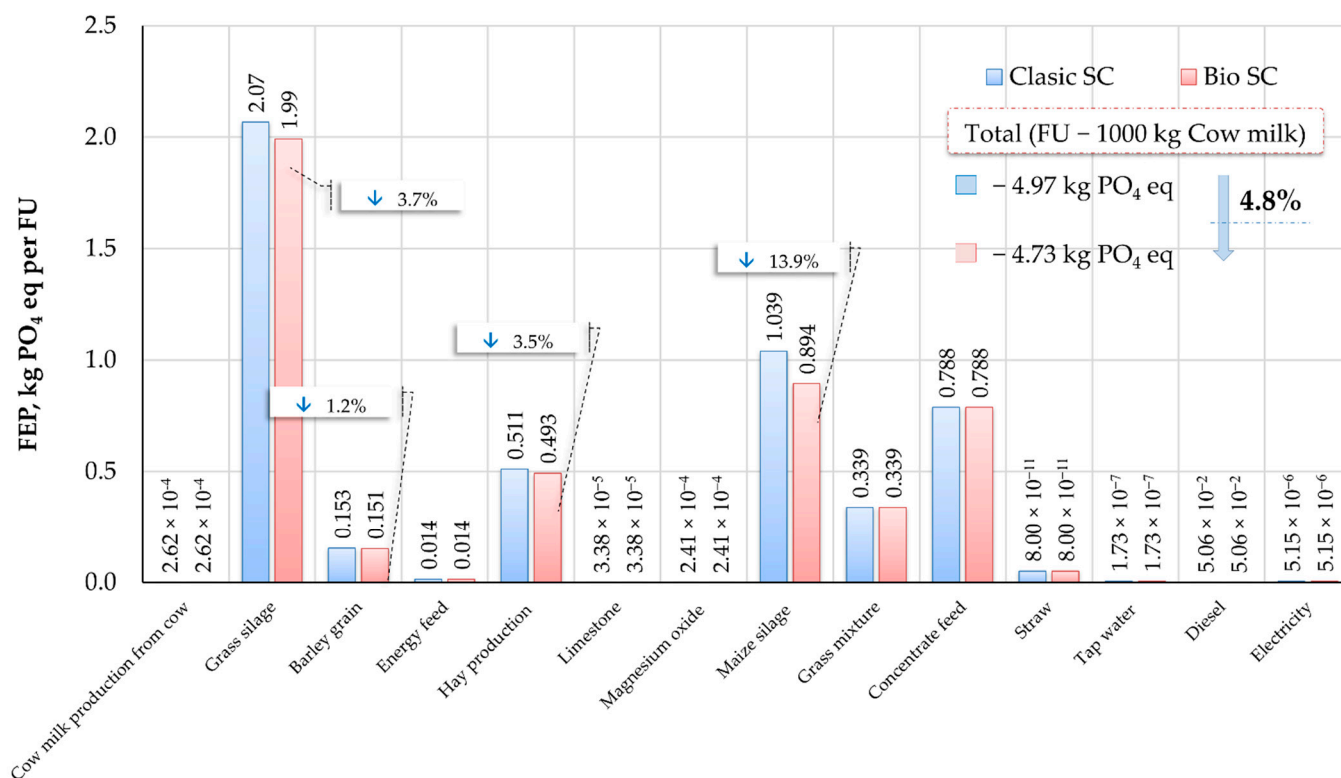


**Figure 5.** TAP of milk production stocks per FU.

In the part of stocks used in grass silage, the sulfur dioxide emission potential was reduced to 36.1% (Classic SC—0.140 kg SO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—0.130 kg SO<sub>2</sub> eq. FU<sup>-1</sup>), barley grain to 7.8% (Classic SC—0.254 kg SO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—0.180 kg SO<sub>2</sub> eq. FU<sup>-1</sup>), and hay production to 30.0% (Classic SC—1.60 kg SO<sub>2</sub> eq. FU<sup>-1</sup>/Bio SC—0.96 kg SO<sub>2</sub> eq. FU<sup>-1</sup>). The use of biopreparations reduced the total TAP of milk production stocks per FU to 19.7% (Bio SC—4.29 kg SO<sub>2</sub> eq. FU<sup>-1</sup>).

Figure 6 shows the potential equivalent impact of stock levels of FU in milk production scenarios on FEP affected by PO<sub>4</sub> compounds (kg PO<sub>4</sub> FU<sup>-1</sup>). The highest PO<sub>4</sub> emissions were found in the part of grass silage milk production stocks, where the PO<sub>4</sub> emissions of this part, which affect FEP, accounted for 41.58% (Classic SC—2.07 kg PO<sub>4</sub> FU<sup>-1</sup>) of the total PO<sub>4</sub> emissions from milk production stocks. The inclusion of biopreparations in the cultivation technology could reduce the environmental impact of this fraction by 3.7% (Bio SC—1.99 kg PO<sub>4</sub> FU<sup>-1</sup>). In the part of the milk production process of the Classic SC maize silage scenario, the amount of PO<sub>4</sub> emissions was 20.89% (Classic SC—1039 kg PO<sub>4</sub> FU<sup>-1</sup>) of the total production of PO<sub>4</sub> compounds, hay production was 15.84% (Classic SC—0.511 kg PO<sub>4</sub> FU<sup>-1</sup>), and barley grain was 3.07% (Classic SC—0.153 kg PO<sub>4</sub> FU<sup>-1</sup>). In the Bio SC scenario, the PO<sub>4</sub> emissions of these parts were reduced by 13.95% (Bio

SC—0.894 kg PO<sub>4</sub> FU<sup>−1</sup>), 3.5% (Bio SC—0.493 kg PO<sub>4</sub> FU<sup>−1</sup>), and 1.2% (Bio SC—0.151 kg PO<sub>4</sub> FU<sup>−1</sup>).



**Figure 6.** FEP of milk production stocks per FU.

The use of biopreparations in the production of milk reduced the FEP to 4.8% (Bio SC—4.73 kg PO<sub>4</sub> eq. FU<sup>−1</sup>). The environmental effects (for FU = 1000 kg of milk) of the other categories of the Bio SC scenario (abiotic depletion, abiotic depletion, ozone layer depletion, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, and photochemical oxidation) are presented in Table 4. The use of biopreparations in the categories reduced the environmental impact from 0.1% to 45.7% in the stocks of milk production technology grass silage, barley grain, hay production, and maize silage.

After changing the share of fertilizers used in the cultivation technology to biopreparations, the scenario for parts of Bio SC stocks such as energy feed, gross; limestone, crushed, washed; magnesium oxide; grass mixture; concentrate feed; protein concentrate, for dairy cows; selenium; sodium chloride, powder; straw; transport; tap water; diesel, burned in agricultural machinery; and electricity mix was not affected.

In both scenarios, the main environmental impacts were linked to grass silage, barley grain, and feed and maize silage. The use of biopreparations in milk production technology reduced the environmental impact from 4.6% to 19.7% in all exposure categories. It mainly affected crops grown for animal feed. Thus, the use of biopreparations could improve the production grown, and also the health of the animals. On the basis of this methodology, many dairy farms can be assessed, and critical points can be addressed in a comprehensive manner. In conclusion, this is a preliminary study to examine whether critical point solutions can contribute to improving the quality of dairy production and the environment.

Our estimated carbon footprint of the sustainable bio-based milk production (0.393 kg CO<sub>2</sub> eq. kg<sup>−1</sup> milk) was lower by 4.6% compared to the average Lithuanian classic dairy farm (0.412 kg CO<sub>2</sub> eq. kg<sup>−1</sup> milk). The results showed that dairy farms have three main sources of exposure: enteric fermentation, production of concentrated feed, and emissions of (organic and mineral) fertilizers [25].

**Table 4.** Environmental impact of other Bio SC impact categories (for FU = 1000 kg of milk).

| Impact Category       | Abiotic Depletion     | Abiotic Depletion | Ozone Layer Depletion | Human Toxicity  | Fresh Water Aquatic Ecotox | Marine Aquatic Ecotoxicity | Terrestrial Ecotoxicity | Photochemical Oxidation                |
|-----------------------|-----------------------|-------------------|-----------------------|-----------------|----------------------------|----------------------------|-------------------------|----------------------------------------|
| No Unit               | 1 kg Sb eq.           | 2 MJ              | 4 kg CFC-11 eq.       | 5 kg 1,4-DB eq. | 6 kg 1,4-DB eq.            | 7 kg 1,4-DB eq.            | 8 kg 1,4-DB eq.         | 9 kg C <sub>2</sub> H <sub>4</sub> eq. |
| Total                 | $1.08 \times 10^{-2}$ | 2588.38           | $2.97 \times 10^{-5}$ | 183.18          | 195.78                     | 22,1117                    | 18.83                   | 0.060                                  |
| Decrease              | ↓ 7.0%                | ↓ 6.6%            | ↓ 5.3%                | ↓ 8.1%          | ↓ 6.4%                     | ↓ 6.5%                     | ↓ 9.0%                  | ↓ 5.3%                                 |
| 1. Grass silage       | $4.43 \times 10^{-3}$ | 433.99            | $4.44 \times 10^{-6}$ | 34.55           | 28.28                      | 37,816                     | 3.79                    | 0.009                                  |
| Decrease              | ↓ 6.8%                | ↓ 15.4%           | ↓ 14.2%               | ↓ 16.6%         | ↓ 15.9%                    | ↓ 14.1%                    | ↓ 13.9%                 | ↓ 13.0%                                |
| 2. Barley grain, feed | $6.20 \times 10^{-4}$ | 115.70            | $1.17 \times 10^{-6}$ | 14.35           | 13.16                      | 13,969                     | 2.05                    | 0.003                                  |
| Decrease              | ↓ 2.3%                | ↓ 10.2%           | ↓ 11.5%               | ↓ 3.5%          | ↓ 1.7%                     | ↓ 3.3%                     | ↓ 0.1%                  | ↓ 10.6%                                |
| 3. Hay production     | $1.05 \times 10^{-3}$ | 200.20            | $1.35 \times 10^{-6}$ | 28.11           | 24.92                      | 35,916                     | 0.63                    | 0.005                                  |
| Decrease              | ↓ 6.7%                | ↓ 8.8%            | ↓ 11.9%               | ↓ 5.4%          | ↓ 4.8%                     | ↓ 3.9%                     | ↓ 18.4%                 | ↓ 6.5%                                 |
| 4. Maize silage       | $2.77 \times 10^{-3}$ | 478.01            | $5.06 \times 10^{-6}$ | 26.59           | 58.39                      | 36,577                     | 1.32                    | 0.011                                  |
| Decrease              | ↓ 12.4%               | ↓ 13.1%           | ↓ 10.8%               | ↓ 21.2%         | ↓ 10.2%                    | ↓ 16.5%                    | ↓ 45.7%                 | ↓ 10.9%                                |



According to our study within certain limits, GWP averaged 0.4 CO<sub>2</sub> eq. The literature review and discussion provided an assessment of other authors and other methods in other countries and different farm types, considering all the animal groups of the herd. In summary, the effect we obtained was on average less than half that of the others, where both smaller and larger ones were obtained than in our study. Summarizing all the evaluations performed, all values range from 0.37 to 2.67 kg CO<sub>2</sub> eq. Under different conditions, a different variation of values was obtained—in America, an average of 2.67 kg CO<sub>2</sub> eq. kg<sup>−1</sup> fat- and protein-adjusted milk (FPCM) with high variability was obtained. Gerber et al. (2010) estimated that the average global emissions from milk production, processing, and farm gate emissions were 2.4 CO<sub>2</sub> eq. per kg FPCM [ $\pm 26\%$ ] [26]. Researchers studying GHG emissions from the dairy sector found that Canada's average final intensity (CF) was 1.07 kg CO<sub>2</sub> eq. L<sup>−1</sup> milk (which could range from 0.86 to 1.14 kg CO<sub>2</sub> eq. L<sup>−1</sup> milk depending on the region). In Portugal, milk production from grazing cows emitted an average of about 0.83 kg CO<sub>2</sub> eq. per kilogram of milk (up to the farm gate) [27].

Williams et al. (2006) [28] estimated that conventional dairy farms in England and Wales had an average value of 1.06 kg CO<sub>2</sub> eq. L<sup>−1</sup> milk, while organic farms had a higher cradle to farm gate intensity of 1.23 kg CO<sub>2</sub> eq. L<sup>−1</sup> milk [19]. Interestingly, Flysjö et al. (2012) [20] stated that a lower rate does not necessarily reflect the real impact on the environment because organic farmers produce more meat per kilogram of milk. Cederberg and Mattson (2000) [29] found that the GWP of organic milk was about 13.6% lower than that of conventional milk. Rotz et al. (2010) [30] calculated the carbon footprint of an inconsistent North American dairy system (dairy farms of various sizes and production strategies) using a dairy GHG software model and found significantly lower GHG intensities (0.37–0.69 kg CO<sub>2</sub> eq. kg<sup>−1</sup> energy adjusted milk), which depended on the level of milk production and the feeding and manure management strategies used.

Increasing milk production through genetic improvement increased GHG emissions per livestock unit (LU, corresponding to one dairy cow) in both dairy systems (3%). However, the increase in milk production (from 6% to 8%) was greater than the increase in GHG emissions from dairy systems. As a result, GHG emissions per unit of product decreased (3–4%) [31].

Assessing the environmental footprint of Alpine milk production chains in the Eastern Alps and the relationship between feed energy conversion, which included herd and manure management, on-farm feed production, purchased feed and materials (dairy), production costs, and milk production (milk processing, dairy), the average GWP per kg of fat- and protein-adjusted milk was 1.19 kg CO<sub>2</sub> eq., GWP and land use changed 1.31 kg CO<sub>2</sub> eq., TAP 17.3 g SO<sub>2</sub> eq., and FEP 6.0 g PO<sub>4</sub> eq. [32].

Disorders in the health and welfare of dairy cows increase the environmental impact of milk production due to the negative impact on cow productivity. One of the welfare problems is heat stress, which is becoming increasingly important even in temperate regions. While improving animal welfare can reduce emissions, the potential for mitigation depends on the environmental costs associated with specific interventions. The combined effects of mechanical ventilation on milk production GWP, TAP, and FEP were small, and the model calculations showed a small reduction in heat stress and the effect of mechanical ventilation on the contribution of milk production to GWP, TAP, and FEP. The potential for thermal stress reduction can at least exceed the environmental costs associated with the manufacture and operation of the fan [33].

The extended LCA for coupled milk and beef production in Latin America, with 1 kg FPCM and 100 g beef as a functional unit (FU) to reflect the current global demand for beef and dairy, considered the complexity of Costa Rica's cattle farming systems. Dual-use farms generate a lower GWP footprint per kg of FPCM plus 100 g of beef than specialized dairy farms, although they still needed more land. The main factor was the structure of the herd, which influences the amount of beef produced and the milk yield per animal, reflecting the level of dairy specialization. This new evidence on the environmental performance of cattle farming systems emphasizes the need to consider milk and beef production, as well

as the many environmental impacts of interlinked milk and beef production systems, when developing sustainable reduction strategies [34].

It was established that the local home-fed regime had the highest C footprint in economic distribution, but this more self-contained system was associated with the lowest footprint using mass distribution and attracted the lowest emissions by area, regardless of milk production. To obtain C footprint values, they can be recalculated from the GWP which we used. Therefore, we did not provide additional C footprint in our work. As it was decided to use an appropriate method for the evaluation of the indicators, we presented other indicators (abiotic depletion, abiotic depletion (fossil fuels), GWP (GWP100a), ozone layer depletion (ODP), human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, TAP, and FEP) and C footprint expressed in GWP CO<sub>2</sub> eq.

Thus, mass- and area-based mitigation assessments are likely to contribute to policy objectives in reducing GHG emissions across the economy [18]. Another study identified the main foci of negative impact on the environment to suggest possible mitigation methods and their economic efficiency. GHG emissions can be reduced through improved pastures, better agricultural management practices, efficient use of fertilizers, and optimal livestock numbers [35].

#### 4. Conclusions

- In order to quantify the potential emissions of the dairy farm using a life cycle assessment method, the results of the processes indicated the critical points which had the highest potential for emissions. Grass silage, maize silage, and concentrate feed were found to account for the largest share of gas emissions, accounting for 26.09% (107.39 kg CO<sub>2</sub> eq. FU<sup>-1</sup>), 22.70% (93.44 kg CO<sub>2</sub> eq. FU<sup>-1</sup>), and 21.85%, respectively.
- Climate-smart technology was adjusted with climate-smart holistic management and critical points were set, where 50% of N fertilizers were replaced by organic bioproducts. The evaluation of the changed technology showed that in the bio scenario, the amount of coal per FU decreased to 21.3% (23.68 kg FU<sup>-1</sup>), natural gas—up to 15.2% (13.29 m<sup>3</sup> FU<sup>-1</sup>), lime—up to 12.4% (40.89 kg FU<sup>-1</sup>), diesel—up to 15.5% (27.36 kg FU<sup>-1</sup>), calcium nitrate—up to 30.9% (6.06 kg FU<sup>-1</sup>), ammonium nitrate—up to 22.5% (1.73 kg FU<sup>-1</sup>), NH<sub>3</sub>—up to 42.7% (7.49 kg FU<sup>-1</sup>), and agricultural machinery—up to 0.6% (3.50 kg FU<sup>-1</sup>).
- The use of biopreparations in the categories reduced the environmental impact from 0.1% to 45.7% in the stockpiles of grass, barley grain, hay production, and maize silage.
- Climate-smart holistic management system reduced environmental impact from 4.6% to 19.7% in all exposure categories. It mainly affected crops grown for animal feed.

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