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An Integrated Analysis of Dairy Farming: Direct and Indirect Environmental Interactions in Challenging Bio-Physical Conditions

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Abstract: The demand for milk and its products is growing worldwide. The need to find more efficient ways to produce milk while reducing pressure on the local and global environment has been identified. The Israeli dairy system operates in a challenging environment (limited land, water, and a harsh climate). This paper embraces a life cycle assessment (LCA) framework to analyze various local and global direct and indirect environmental interactions of milk production in Israel. The results show that the production of 1 kg of fat and protein-corrected milk (FPCM) in the systems that were analyzed requires on average 0.5 m² of land, 52 L of water, and 3.3 MJ of energy. The emissions that were generated over the life cycle averaged 1.03 kg CO₂-eq (GWP), 0.0095 kg SO₂-eq (AP) and 0.003 kg PO₄-eq (EP). The research findings point to several ‘pollution hotspots’ that are relevant also to dairy systems in other regions, including feed supply, GHG emissions that are related to enteric fermentation, manure management, and the use of water, and discuss some potential directions to advance more efficient, less polluting system.

Keywords: dairy production; life cycle assessment; Israel; environmental impact

1. Introduction

Worldwide, the demand for dairy products has been growing in recent years, and this is expected to continue given demographic and economic process [1]. Various studies have analyzed the significant loads on local and global environmental systems that livestock create [2,3]. Considerable attention has been given to livestock’s role in GHG emissions and climate change processes. It has been estimated that dairy cows contribute about 20% of the overall livestock GHG emissions, about 4% of all anthropogenic emissions [4,5]. However, dairy systems have several environmental interactions of which GHG emissions are but one. For example, the use the resources (e.g., land, water, energy) that are required to grow feed crops contaminate soil and water with large amounts of solid and liquid waste and create air pollution throughout the entire life cycle of the product [6,7].

Recognition of the need to examine the direct and indirect, local and global environmental interfaces of dairy is gaining ground. A growing number of studies have advanced a life cycle assessment (LCA) approach for examining dairy production systems at various scales and stages e.g., [8–11] (see Tables S1 and S2 in the Supplementary Materials file for an overview of a wider list of dairy-related LCA-based studies). That recognition has led to promoting a standardization procedure and recommendations for dairy LCA studies, including recommendations for analysis procedures, allocation methods at the various stages, and the use of uniform indicators of environmental impact [12–15]. This approach can identify the environmental hotspots in the systems that are being considered [16], and then generate awareness among various stakeholders, contribute to reducing impact, and promote sustainable systems.
This paper is the first to systematically analyze the environmental impact of milk production in Israel. An in-depth analysis of the Israeli milk production system may contribute to understanding processes that are also relevant in other regions, because:

1. Israeli dairy cows are characterized by having some of the highest yields in the world. While the average world production ranges from 5000–9000 kg of milk per cow per year, the average Israeli cow produces 11,600 kg [17].
2. Milk production in Israel contends with complex environmental conditions that include the limited availability of land and water resources, and challenging climatic conditions (e.g., high temperatures and humidity in the summer months).
3. In recent years, the State of Israel has promoted a comprehensive reform of the dairy sector aiming to make it more economically efficient and reduce its environmental impacts [18]. This reform included, inter alia, improving sewage system infrastructure, establishing manure treatment facilities including composting, and building a facility for treating agricultural sludge [18]. Each of these components is relevant to many other regions in the world that face changes both in the demand for milk and dairy products and in the environmental conditions for milk production because of declining availability of resources, climate change, etc.

Overall, the Israeli dairy sector is based on about 117,000 cows, that produce almost 1.5 billion liters of milk annually [19]. The main breed of cow that is raised is Holstein-Parisian-Israeli, which has been genetically adapted to the Israeli climate. The Israeli dairy feeding system does not include grazing, and is based on measured, uniform portions throughout the year. The total mix ratio (TMR) of the Israeli dairy cow diet consists of approximately 35% roughage and remains from the food industry (local feed) and approximately 65% concentrated feed (imported) [18].

To date, only one study [9] that compared the GHG emissions from dairy farms in various countries addressed the case of Israel; it found that milk production in Israel has the lowest level of emissions. However, the study was based on data from a typical small Israeli farm (with only 63 cows) and did not cover the entire life cycle of the milk. For example, the issue of water that is needed throughout the milk production life cycle, an important issue in the Israeli context and increasingly relevant to many other regions, has not been addressed. While the need to include the water component is receiving growing attention in dairy-related LCA studies, it is still limited compared to other components [10].

The Israeli dairy production system has not been examined in a holistic way that includes the direct and indirect effects of the product throughout the entire life cycle, assesses the influence of various stages and components, and identifies the potential for reducing its impact. It follows that the aim of the research that is presented in this paper is to assess the environmental impacts of milk production in Israel and identify hotspots in its life cycle. The study included 12 dairy farms in different parts of the country. After presenting the findings from the Israeli systems that were studied, it compares these results to similar studies around the world.

2. Materials and Methods

The research followed the overall method that was presented by ISO 14040 [16] and the research steps suggested by the International Dairy Federation (IDF), in partnership with the Food and Agricultural Organization (FAO) Livestock Environmental Assessment and Performance (LEAP) [12,13,15].

The research objective was to assess the environmental impacts of milk production systems in Israel and identify hotspots in the production chain. The scope of the research was from “cradle to gate”, beginning with the extraction of raw materials and concluding when the raw milk reaches the dairy factory gate.

Figure 1 illustrates the system boundaries in the study.

The functional unit is 1 kg of fat and protein corrected milk (FPCM). The energy content is that of standard milk with 4% fat content and 3.3% protein.
2.1. System Boundaries

The climate in Israel is considered subtropical, with cold, rainy winters and summers that are hot and humid on the coastal plain, but hot and dry in the valleys and the southern region. The research examined 12 dairy farms in different areas of the country, including different herd sizes. The necessary data were gathered by interviewing the farmers and receiving supporting data from each farm over the course of a year.

2.1.1. Feed Production

The feed composition is largely based on a range of crops (e.g., maize, wheat, soybean) that originate in different parts of the world (e.g., domestic, North America, Eastern Europe). The resources that are used to grow feed and the resultant by-products differ from place to place. Forage (e.g., silage and hay) is locally grown while concentrates (grains and meals) are mostly imported. In addition, a large proportion of agricultural residue and food industry waste is used.

2.1.2. Milk Production

The Israeli herd is monitored digitally. Data on the milk yield and quality, as well as the cows’ fertility and health are constantly documented by special software that is managed by the Israeli Cattle Breeders Association (ICBA). Detailed information on the relevant herd characteristics is provided in Table 1. The on-site operation includes daily drinking and feeding the cows, and ongoing climate control (mostly cooling systems). Some farms have a local, on-farm feed center while others receive feed from a regional feed center.

2.1.3. Manure Management

Approximately 70% of the manure that is generated is wet. There are several treatment approaches including: (a) manure storage pit: manure is stored in a pit and occasionally emptied into nearby fields. (b) Composting: manure is transported to a nearby composting facility. (c) Anaerobic digestion facility: manure is transported daily to one of the country three facilities where it used to produce biogas. The remaining 30% of the manure from cow
sheds is dry manure that is treated by daily cultivation, a composting process that reduces odors, flies, and the excretion of manure into the fields (the “Harduf Model”). Once a year the remaining manure residues are spread in nearby fields [20].

### Table 1. Primary data for the participating dairy farms (per year).

| Item                  | Unit            | Avg.  | A    | B     | C     | D     | E     | F     | G     | H     | I     | J     | K     | L     |
|-----------------------|-----------------|-------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Herd size             | Number of cows  | 1051  | 545  | 601   | 528   | 634   | 999   | 1210  | 982   | 1136  | 724   | 1734  | 1562  | 1957  |
| Milk production       | Kg FPCM/cow      | 6366  | 6430 | 5854  | 6428  | 6441  | 7099  | 6349  | 6007  | 6129  | 6338  | 6633  | 7427  | 5257  |
| Milk yield            | Kg FPCM/cow      | 12,783| 12,703| 11,433| 12,977| 13,272| 13,300| 12,648| 12,490| 12,829| 13,583| 14,731| 11,376|
| DMI                   | Kg DM/cow/day    | 16.76 | 17.05| 16.48 | 17.32 | 14.84 | 17.01 | 16.03 | 14.46 | 20.83 | 16.54 | 18.09 | 17.68 | 14.80 |
| Ration composition    | Concentrate %    | 41    | 36   | 37    | 36    | 42    | 37    | 32    | 42    | 63    | 43    | 40    | 38    | 35    |
|                       | Forage %         | 42    | 51   | 55    | 34    | 44    | 55    | 27    | 49    | 27    | 46    | 48    | 49    | 33    |
|                       | Food industry %  | 13    | 5    | 5     | 22    | 10    | 5     | 33    | 5     | 10    | 6     | 5     | 8     | 32    |
|                       | Other (feed     | 4     | 8    | 3     | 8     | 4     | 3     | 8     | 4     | 0     | 5     | 7     | 5     | 0     |
|                       | additives)       |       |      |       |       |       |       |       |       |       |       |       |       |       |
| Total farm area       | m²               | 52,000| 40,000| 30,000| 38,000| 30,000| 40,000| 60,000| 38,000| 40,000| 35,000| 124,000| 86,000| 66,000|
| Water use             | m³               | 47,110| 26,450| 29,438| 27,095| 43,111| 55,188| 40,700| 41,600| 40,200| 42,133| 71,306| 102,132| 44,482|
| Electric use          | kWh              | 646,385| 242,117| 242,510| 308,249| 451,263| 378,488| 599,500| 769,130| 751,000| 508,407| 1,204,400| 1,241,639| 949,917|
| Diesel use            | L                | 28,243| 13,800| 8090  | 24,287| 12,720| 14,704| 47,000| 6000  | 13,153| 9599  | 71,670| 59,695| 58,200|

2.1.4. Transportation

This study documents the inputs into and emissions from transport in all stages of dairy production including: (a) sea freight for imported feed from major exporting countries; and domestic transport of (b) feed from the port or field to the regional or local feed center; (c) industry remains from factories across the country to feed centers; (d) feed from regional food centers to farms; (e) milk from farms to dairy factories; (f) slurry/manure to the anaerobic digestion facility or regional composting facility; and (g) carcasses to the national animal containment facility.

2.2. Allocation and Extraction

Milk is the major product of the dairy farm and meat is a co-product, therefore, this research used a physical allocation to divide the demand for resources and related pollutions. The allocation represents demand for feed and is based on the weight of milk and meat. Moreover, part of the feed consists of co-products from other agriculture or food systems. For these components, an economic allocation was used for feed production based on the relative average price of kg co-product ingredient [15]. This study did not include the effects of infrastructure, machinery, antibiotics, and hormones. Other dairy-related studies highlighted the limited contribution of these components [8,21,22]. While this study included wastewater quantities and related emissions, it did not include any further use of the wastewater and treated waste use of biogas that milk production generates.

2.3. Inventory Data (LCI)

Data on all the inputs and the related outputs of each stage in the systems that were analyzed were calculated using information that was received from the farms, as well as secondary sources. The farm data included monthly summaries regarding herd characteristics (e.g., number of animals in each age group, milk yield, fat and protein content, dead animals, feed rations), and the use of resources as reported by the farm utility bills (i.e., electricity, water and diesel). Other required data and environmental coefficients were collected from interviews with farmers and other professionals, as well as statistical reports and information from professional bodies such as the Ministry of Agriculture (MOAG) and the Israeli Dairy Boards (IDB). Missing information was completed using the Ecoinvent 2.2 Lifecycle Analysis Research Database and research literature on the subject.
Tables 2 and 3 present the primary and secondary data (1, 2) and key factors (3) that were used in the analysis (Further information about the data and conversion procedure can be found in Tables S3–S5 in the Supplementary Materials file).

Table 2. Conversion factors.

| Unit | Land Use (m²) | Water Use (m³) | Energy Use (MJ) | GWP (kg CO₂-eq) | AP (kg SO₂-eq) | EP (kg PO₄-eq) | Reference |
|------|---------------|----------------|-----------------|-----------------|---------------|---------------|-----------|
| Local feed production | Diesel (in-field) | L | 36.8 | 2.66 | 0.01 | 0.002 | [23] |
| | Wastewater treatment | m³ | 2.12 | 0.39 | 0.0013 | 0.0001 | [24] |
| | Fertilizer production | N | 0.07 | 0.009 | 59.5 | 4.57 | 0.015 | 0.0056 | [25] |
| | | P | 0.08 | 0.1 | 26 | 2.025 | 0.033 | 0.045 | [2] |
| | | K | 0.05 | 0.007 | 8 | 0.5 | 0.002 | 0.0007 | [2] |
| | Insecticide production | kg | 0.35 | 0.122 | 257 | 16.67 | 0.1 | 0.0676 | [2] |
| | Herbicide production | kg | 0.24 | 0.085 | 164 | 10.25 | 0.11 | 0.0276 | [2] |
| | Marine transport | tkm | 0.15 | 0.01 | 0.0002 | 0.00002 | [26] |
| | Electricity production in Israel | MJ | 0.037 | 0.185 | 0.0006 | 0.000047 | [26] |
| | Land transport in Israel | km | 22 | 0.5 | 0.0015 | 0.00028 | [27] |
| | Regional feed center | ton TMR | 1.62 | 3 kwh | 0.0003 L of diesel | [20] |
| | Manure management | | | | | | |
| | Regional compost facility | m³ input manure | 0.67 | 1.16 L of diesel | [20] |
| | Anaerobic digestion facility | m³ input manure | 0.36 | | | | |

Table 3. The impact categories that were included in the research.

| Impact Category | Measured Unit | Contributing Substance | Characterization Factor | References |
|-----------------|---------------|------------------------|-------------------------|------------|
| Land use | m² | Land use for growing feed and dairy farm | | |
| Water use | m³ | Blue water footprint including water use for growing feed and for cow shed | | |
| Energy use | MJ | Use of diesel and electricity | | |
| Climate change (Global warming potential GWP) | kg CO₂-eq | CO₂ | 1 | [28] |
| | | CH₄ | 25 | |
| | | N₂O | 298 | |
| | | SO₂ | 1 | |
| Acidification potential (AP) | kg SO₂-eq | NH₃ | 1.88 | [25] |
| | | NOₓ | 0.7 | |
| | | PO₄ | 1 | |
| | | NH₃ | 0.35 | |
| Atrophy cation potential (EP) | kg PO₄-eq | NOₓ | 0.13 | [25] |
| | | NO₃ | 0.1 | |
| | | P | 3.06 | |

The data that were gathered from the studied farms was converted into the potential environmental impact of each phase of the systems under consideration. Table 3 lists the selected impact categories [8,14] and their characterization factors. For calculating the contribution to GHG emissions, tiers 1 and 2 of the IPCC method were implemented [28]; see the Supplementary Materials file.
3. Results

The current research found that the studied systems required, on average, 0.5 m² of land, 52 L of water, and 3.3 MJ of energy to produce 1 kg FPCM. The emissions that were generated over the life cycle were 1.03 kg CO₂-eq (GWP), 0.0095 kg SO₂-eq (AP), and 0.003 kg PO₄-eq (EP).

Figure 2 presents the share of each stage of the system in the milk production life cycle. Feed production, especially concentrated feed, was found to be a significant component of resource use (98% of the total land used, 87% of water, and 58% of the energy inputs). Most of that usage is located in the countries from which the feed is imported (mostly, US, Ukraine, and Russia). The impact of domestic feed production is mostly the result using of fertilizers and pesticides when growing forage. While the use of resources for feed production also has implications for related emissions, it seems that other than EP (55%), most emissions are from the farm stage, especially enteric fermentation (46% of the total GWP) and manure management (69% of the total AP).

Table 4 presents further analysis and a detailed inventory of the inputs and related by-products throughout the milk LCA (data at the specific farm level can be found in the Supplementary Materials file). As noted above, the vast majority of land and water inputs are related to feed production (0.49 m² and 0.045 m³, respectively), primarily production of concentrated feed (0.33 m² and 0.032 m³ respectively). Feed production also uses a significant amount of energy inputs, averaging 57% of the energy that is used by the systems throughout the life cycle. Both transportation (0.68 MJ) and dairy farm operations (0.67 MJ) are important as well (24% and 17%, respectively). In terms of the generated emissions, the two main sources of GHG emissions are enteric fermentation (0.468 kg CO₂-eq) and manure management (0.242 kg CO₂-eq), which together are responsible for 69% of the GHG emissions, particularly direct emissions of N₂O. Manure is also a main contributor of AP and potential water contamination (41%). The other main source of EP is feed production, of which 60% occurs overseas.

Figure 3 presents the range of results for the analyzed systems. The differences between the systems are the result of several factors including, but not limited to, geographical location, size, varied management in each farm, feed composition, and type of manure management (for detailed results at the specific farm level please see the Supplementary Materials file). The figure also shows (in blue) how the current findings compare to the range of results in previous studies in other locations (see the Supplementary Materials file). In most of the categories that were examined, the systems that were examined here were found to be more efficient than the global range.

Table 4. Environmental impact of 1 kg FPCM produced by the systems studied.

| Feed production | LU (m²) | WU (m³) | EU (MJ) | GWP (kg CO₂-eq) | AP (kg SO₂-eq) | EP (kg PO₄-eq) |
|-----------------|---------|---------|---------|-----------------|----------------|----------------|
| Feed production |         |         |         |                 |                |                |
| Sum             | 0.493   | 0.045   | 1.872   | 0.2             | 0.00203        | 0.0016         |
| Forages         | 0.167   | 0.013   | 0.241   | 0.037           | 0.00104        | 0.00060        |
| Fertilizer and  |         |         |         |                 |                |                |
| pesticide       |         |         |         |                 |                |                |
| production and  |         |         |         |                 |                |                |
| application at  |         |         |         |                 |                |                |
| field           |         |         |         |                 |                |                |
| Wastewater      |         |         |         |                 |                |                |
| treatment for   |         |         |         |                 |                |                |
| irrigation      |         |         |         |                 |                |                |
| diesel use at   |         |         |         |                 |                |                |
| field           | 0.198   | 0.031   | 0.00102 |                |                | 0.00060        |
| Concentrated    |         |         |         |                 |                |                |
| feed           | 0.327   | 0.032   | 1.631   | 0.163           | 0.0001         | 0.001          |
| Forages         | 0.028   | 0.005   | 1.8 x 10⁻⁵| 1.3 x 10⁻⁶      |                |                |
| Fertilizer and  |         |         |         |                 |                |                |
| pesticide       |         |         |         |                 |                |                |
| production and  |         |         |         |                 |                |                |
| application at  |         |         |         |                 |                |                |
| field           | 0.015   | 0.001   | 4.3 x 10⁻⁶| 8.0 x 10⁻⁷      |                |                |
| Wastewater      |         |         |         |                 |                |                |
| treatment for   |         |         |         |                 |                |                |
| irrigation      |         |         |         |                 |                |                |
| diesel use at   |         |         |         |                 |                |                |
| field           | 0.163   | 0.001   | 1.3 x 10⁻⁵| 8.0 x 10⁻⁷      |                |                |
Table 4. Cont.

|                        | LU (m²) | WU (m³) | EU (MJ) | GWP (kg CO₂-eq) | AP (kg SO₂-eq) | EP (kg PO₄-eq) |
|------------------------|---------|---------|---------|-----------------|----------------|---------------|
| Milk production        |         |         |         |                 |                |               |
| Regional feed center   | Sum     | 0.008   | 0.007   | 0.674           | 0.55           | 0.00032       |
| Dairy farm             | Sum     | 0.001   | 1.8 × 10⁻⁵ | 1.8 × 10⁻⁶ | 6.5 × 10⁻⁹ | 8.9 × 10⁻¹⁰ |
|                        | Enteric fermentation |         | 0.007   | 0.673           | 0.55           | 0.00032       | 2.67 × 10⁻⁵ |
|                        | Operation |         |         | 0.001       | 0.025           | 0.00648       | 0.00121     |
|                        | Direct   | 0.436   | 0.066   | 0.00023      | 2.12 × 10⁻⁵    |                |              |
|                        | Electricity | 0.306   | 0.057   | 0.00019      | 1.45 × 10⁻⁵    |                |              |
|                        | Diesel   | 0.130   | 0.009   | 3.62 × 10⁻⁵  | 6.70 × 10⁻⁶    |                |              |
|                        | Indirect | 0.237   | 0.015   | 9.28 × 10⁻⁵  | 5.55 × 10⁻⁶    |                |              |
|                        | Electricity production |         | 0.012   |               |                |               |              |
|                        | Water production |         | 0.226   | 0.015         | 9.28 × 10⁻⁵    | 5.55 × 10⁻⁶    |              |
| Manure management      | Sum     | 0.001   | 0.025   | 0.242         | 0.00648        | 0.00121       |
|                        | Operation |         |         | 0.066       | 0.00026        | 4.73 × 10⁻⁵    |              |
|                        | Direct emission from manure |         | 0.176   |               | 0.00623        | 0.00116       |              |
|                        | CH₄      | 0.144   | 10−⁶    |              |                |               |              |
|                        | N₂O      | 0.032   | 10−⁶    |              |                |               |              |
|                        | N₂O      | 0.140   | 10−⁶    |              |                |               |              |
|                        | N₂O      | 0.004   |         |              |                |               |              |
| Transport              | Sum     | 0.684   | 0.035   | 0.00067      | 7.4 × 10⁻⁵     |              |              |
|                        | Feed transportation |         | 0.588   | 0.033        | 0.00066        | 7.3 × 10⁻⁵    |              |
|                        | Marine transportation |         | 0.419   | 0.029        | 0.00065        | 7.1 × 10⁻⁵    |              |
|                        | Land transportation |         | 0.169   | 0.003        | 1.0 × 10⁻⁵     | 1.9 × 10⁻⁶    |              |
|                        | Milk transportation |         | 0.059   | 0.001        | 4.4 × 10⁻⁵     | 8.1 × 10⁻⁷    |              |
|                        | Manure transportation |         | 0.027   | 0.001        | 1.8 × 10⁻⁵     | 3.3 × 10⁻⁷    |              |
|                        | Carcasses transportation |         | 0.010   | 2.3 × 10⁻⁴  | 7.1 × 10⁻⁷     | 1.3 × 10⁻⁷    |              |
|                        | Sum      | 0.502   | 0.052   | 3.254         | 1.027          | 0.0095        | 0.00291     |

Figure 2. The share (%) of various stages in the milk production LCA.
Figure 3. Results for the selected environmental impacts throughout the LCA of 1 kg FPCM: systems in Israel versus global results.

4. Discussion

The demand for milk and its products is growing worldwide. The Israeli case, on which the research that is presented in this paper focuses, can contribute to advancing the sustainability of dairy systems, both locally and in other countries. The research findings point to several environmental hotspots, which should facilitate identifying and promoting measures to reduce environmental impact. The Israeli dairy system operates in a challenging environment but nevertheless presents significant achievements, both in terms of high milk production capability and environmental performance, compared to other dairy systems around the world. Current and expected climate change processes and decreased availability of resources will require production systems to find more efficient methods that also reduce pressure on the local and global environment. Analysis of the Israeli system can provide an example and help to guide development in this direction.

Recent review papers emphasized the challenge to compare the results of different studies given the differences between the research boundaries, data quality, and specific methods studies [7,8,13]. Nevertheless, the range of results can be compared and identify the ‘environmental performances’ of different studied systems [7].

These research findings highlight that milk production in Israel is within the global range for most of the environmental categories that were analyzed and presents even better performances per unit of milk in some categories (see Figure 3 and Table S1 in the Supplementary Materials file). For example, while the range of land that is required for a unit of milk in previous studies is 0.8 m² to 2.5 m², the average land that is required in the studied systems is 0.5 m², and for some farms as low as 0.3 m². Similar gaps can be identified in the case of GHG emissions. Reviewed studies reported a range of emissions between 0.7 kg CO₂e up to 2.3 kg CO₂e, while this study found emissions at the lower range between 0.7 to 1.4 kg CO₂e. The results are probably due, inter alia, to the characteristically high-yield of Israeli cows, which reduces both the inputs necessary and emissions per unit of milk. Another factor is the relatively large use of by-products, mostly from the food
industry but also from agriculture, for feeding the cows (13% of the average ration), which decreases the resources and emissions that are associated with feed crops because fewer crops are grown specifically to feed dairy cows. Moreover, the land area that is required for milk production is relatively low due to the lack of grazing.

Some of the hotspots identified in this study are similar to those highlighted in studies in other parts of the world including emissions from enteric fermentation, manure management and feed production e.g., [7,11,13,29]. However, some positive and negative unique hotspots were also identified including use of land, water and farm management as discussed in the following paragraphs.

Feed composition accounts for a significant part of the environmental impacts of the systems that were considered in this study. Similar to previous studies e.g., [11,29] that component has implications for all the measured categories including land and water use and all emissions. Uniquely, the research addressed the source of the geographical source of the feed and its related environmental implications. Much of the feed that is used in the studied systems is imported concentrated feed, which generates environmental pressure in the regions where the crops are grown, on a global scale. For example, much of the AP is found in the Mississippi River Basin and the Black Sea region in Eastern Europe [30,31]. Considering the specific environmental implications of different growing regions and adjusting the feed composition could minimize their impact.

Manure management of dairy farms in Israel receives considerable attention and has indeed been found to have a significant impact, mainly on the quality of waste-water and air emissions. In fact, because a significant part of the feed does come from domestic sources, the potential for promoting alternative methods and sources could reduce some of the effects that are caused by fertilizers and manure management. Given the limited availability of data, this study did not examine the use of manure by-products as a substitutes for the use of chemical fertilizers in agricultural fields, by spreading manure in fields, or using compost or using fertilizer products that are produced by agricultural sludge treatment facilities. Therefore, there is potential for “closing the circle” of stages in the system and assessing the possible reduction of environmental impact.

On-farm milk production has a variety of effects that are related to energy and water consumption, emissions from the cows’ digestive system, solid waste (manure), and sewage. Already today, a significant share of Israeli dairy farms use cowshed roofs for photovoltaic energy generation, which may lead to offsetting some energy consumption from unrenewable sources and the related emissions. Minimizing the implications (odors, contamination) of manure is another challenge that farmers face. One widely-used approach involves cultivating the manure on-site (the “Harduf Model”) at the cowshed a few times every day.

Water use. As noted, most studies address the issue of the water that is used in the LCA for dairy production only partially. Israel’s geographical location between a desert and a Mediterranean climate influences the availability of water and motivates attempts to optimize its use. As the study shows, the average water use per 1 kg FPCM is 52 L, mostly related to domestic and international feed production. Although approximately one-third of the water that is used domesticaly is for feed production, most of that amount is treated waste-water. The “imported” water is consumed in the countries from which the concentrated feed is sourced, making this a matter of importance from a global perspective, highlighting that imported feed influences water sources in other parts of the world. Water for the cows to drink and for cleaning the dairy farm account for roughly 13% of the water consumption along the life cycle of 1 kg FPCM, with double the amount of water consumed in the summer months than in winter.

Similar to previous studies, the main focus of the analyses that are presented in this paper was one unit of milk. However, the analysis can also be the base for wider national scale evaluation that can allow understanding the overall magnitude of the studied system and comparing it to other activities/sectors. While future research should expand the scope of the studied farms to reflect the full composition of the producing systems (size, location,
practices etc.) the current study results suggest that the overall resources that are required for the Israeli demand for milk are approximately 75,000 Ha of land and 78 million m$^3$ of water and generates 1.5 million tons of CO$_2$e. While most of the land and water are used in overseas regions from which Israel imports feed products, most of the emissions are related to the dairy farms and the cows themselves (e.g., enteric fermentation, manure) in Israel.

5. Conclusions

Based on the systems that were included in this study, milk production in Israel is within the global range for most of the environmental categories that were analyzed and shows better performances per unit of milk in some categories.

Following the research findings and identification of these environmental hotspots, it is necessary to further examine measures for streamlining and improving the environmental performance of the milk production system in Israel, at the national level and at the specific farm level. However, to be able to implement such improvement at the national scale, future research should expand the number of studied systems that are analyzed beyond the number that were analyzed in this study.

Nevertheless, as environmental constraints are increasing worldwide, following the results of the current study, it seems that the Israeli dairy system illustrates the ability to advance an efficient system, one that can signal directions for dairy systems in other countries that are interested in, or forced, to advance more sustainable measures and performance.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12040480/s1, Table S1: an overview of a number of LCA studies for milk published between the years 2003–2020 and examined a number of environmental impacts; Table S2: an overview of a number of LCA studies for milk published between the years 2003–2020 and examined only GWP; Table S3: for fertilized application in Israel; Table S4: fermentation. Based on hard characterization and DMI characterization for each group hard. IPCC 2006 tier 2- category 3A1; Table S5: manure management: dry- daily spread (DS); wet- solid storage (SS), composting—intensive windrow (C), anaerobic digester (AD).

Author Contributions: Conceptualization, S.T., M.K.; methodology, S.T., M.K.; formal analysis, S.T.; investigation, S.T.; resources, S.T.; data curation, S.T.; writing—original draft preparation, S.T., M.K. writing—review and editing, S.T., M.K.; visualization, S.T., M.K.; supervision, M.K.; project administration, M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the Israeli Dairy Board grant number 892-0001-16.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The research was partially funded by the Israeli Dairy Board. The research was professionally supported by the Israeli Ministry of agriculture and rural development extension services unit.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. OECD; FAO. OECD-FAO Agricultural Outlook 2020–2029; FAO: Rome, Italy; OECD Publishing: Paris, France, 2020. [CrossRef]
2. Nijdam, D.; Rood, T.; Westhoek, H. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy 2012, 37, 760–770. [CrossRef]
3. Poore, J.; Nemecek, T. Reducing food’s environmental impacts through producers and consumers. Science 2018, 360, 987–992. [CrossRef] [PubMed]
4. FAO. Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment; FAO: Rome, Italy, 2010.
5. FAO. Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities; FAO: Rome, Italy, 2013.
6. IDB; ICBA. The Dairy Industry in Israel 2008; Hojman, D., Malul, Y., Avrech, T., Eds.; Israel Dairy Board & Israel Cattle Breeders Association: Yehud, Israel, 2008.

7. Roy, P.; Nei, D.; Orkais, T.; Xu, Q.; Okadome, H.; Nakamura, N.; Shiina, T. A review of life cycle assessment (LCA) on some food products. J. Food Eng. 2009, 90, 1–10. [CrossRef]

8. Baldini, C.; Gardoni, D.; Guarino, M. A critical review of the recent evolution of life cycle assessment applied to milk production. J. Clean. Prod. 2017, 140, 421–435. [CrossRef]

9. Hagemann, M.; Hemme, T.; Ndambi, A.; Alqaisi, O.; Sultana, M.N. Benchmarking of greenhouse gas emissions of bovine milk production systems for 38 countries. Anim. Feed Sci. Technol. 2011, 166–167, 46–58. [CrossRef]

10. Ibidhi, R.; Salem, H.B. Water footprint of livestock products and production systems: A review. Anim. Prod. Sci. 2020, 60, 1369–1380. [CrossRef]

11. Baldini, M.; Da Borso, F.; Rossi, A.; Taverna, M.; Bovolenta, S.; Piasentier, E.; Corazzin, M. Environmental sustainability assessment of dairy farms rearing the Italian simmental dual-purpose breed. Animals 2020, 10, 296. [CrossRef] [PubMed]

12. FAO. Environmental Performance of Animal Feeds Supply Chains: Guidelines for Assessment. Livestock Environmental Assessment and Performance Partnership; FAO: Rome, Italy, 2016.

13. European Dairy Association. Product Environmental Footprint Category Rules for Dairy Products; European Dairy Association: Brussels, Belgium, 2018.

14. IDF. Guide on Life Cycle Assessment towards Sustainability in the Dairy Chain; International Dairy Federation: Brussels, Belgium, 2005.

15. IDF. A Common Carbon Footprint Approach for Dairy: The IDF Guide to Standard Lifecycle Assessment Methodology for the Dairy Sector; International Dairy Federation: Brussels, Belgium, 2010.

16. ISO. ISO 14040 Environmental Management—Life Cycle Assessment—Principles and Framework; ISO: Geneva, Switzerland, 2006.

17. FAO; IDF; IFCN. World Mapping of Animal Feeding Systems in the Dairy Sector; FAO: Rome, Italy; IDF: Brussels, Belgium; IFCN: Rome, Italy, 2014.

18. Israel Ministry of Agriculture and Rural Development (MOAG). Israel Agriculture: Overview of Major Aspects MOAG; Israel Ministry of Agriculture and Rural Development (MOAG): Bet Dagan, Israel, 2013.

19. IDB. The Israeli Dairy Board Yearbook 2019: Israel Dairy Board: Yehud, Israel, 2019.

20. Israel Ministry of Agriculture and Rural Development (MOAG). By-Products in Israeli Agriculture: A Concluding Document; Israel Ministry of Agriculture and Rural Development (MOAG): Bet Dagan, Israel, 2013.

21. Meul, M.; Van Middelaar, C.E.; de Boer, I.J.M.; Van Passel, S.; Fremaut, D.; Haesaert, G. Potential of life cycle assessment to support environmental decision making at commercial dairy farms. Agric. Syst. 2014, 131, 105–115. [CrossRef]

22. Yan, M.J.; Humphreys, J.; Holden, N.M. An evaluation of life cycle assessment of European milk production. J. Environ. Manag. 2011, 92, 372–379. [CrossRef] [PubMed]

23. EPA. Life Cycle Inventory (LCI) Data—Treatment Chemicals, Construction Materials, Transportation, On-Site Equipment, and Other Processes for Use in Spreadsheets for Environmental Footprint Analysis (SEFA); U.S. Environmental Protection Agency, Office of Research and Development: Cincinnati, OH, USA, 2016.

24. Opher, T.; Friedler, E. Comparative LCA of Decentralized Wastewater Treatment Alternatives for Non-Potable Urban Reuse. J. Environ. Manag. 2016, 182, 464–476. [CrossRef]

25. Ecoinvent Centre. Ecoinvent 2.2 Database; Swiss Centre for Life Cycle Inventories: Dübendorf, Switzerland, 2010.

26. IEC. Environmental Report for 2014–2015. 2016. Available online: https://www.iec.co.il/environment/Documents/IECEnvironmentalReport122016.pdf (accessed on 1 March 2020).

27. Israel Ministry of Environmental Protection (MEP). Auxiliary Calculator for Calculating Emissions of Air Pollutants from Vehicle Fleets. 2014. Available online: https://www.gov.il/he/departments/general/calculation_methodology (accessed on 1 March 2020). (In Hebrew)

28. IPCC. Guidelines for National Greenhouse Gas Inventories Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland, 2006.

29. Gislon, G.; Ferrero, F.; Bava, L.; Borreani, G.; Dal Pra, A.; Pacchioli, M.T.; Tabacco, E. Forage systems and sustainability of milk production: Feed efficiency, environmental impacts and soil carbon stocks. J. Clean. Prod. 2020, 260, 121012. [CrossRef]

30. Fridman, D.; Kissinger, M. An integrated biophysical and ecosystem approach as a base for ecosystem services analysis across regions. Ecosyst. Serv. 2018, 31, 242–254. [CrossRef]

31. Kissinger, M.; Gottlieb, D. Place oriented ecological footprint analysis—The case of Israel’s grain supply. Ecol. Econ. 2010, 69, 1639–1645. [CrossRef]