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Analyzing the biophysical inputs and outputs embodied in global commodity chains - the case of Israeli meat consumption

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Abstract

The prevailing global livestock industry relies heavily on natural capital and is responsible for high emissions of greenhouse gases (GHG). In recent years, nations have begun to take more of an active role in measuring their resource inputs and GHG outputs for various products. However, up until now, most nations have been recording data for production, focusing on processes within their geographical boundaries. Some recent studies have suggested the need to also embrace a consumption-based approach. It follows that in an increasingly globalized interconnected world, to be able to generate a sustainable food policy, a full systems approach should be embraced. The case of Israeli meat consumption presents an interesting opportunity for analysis, as the country does not have sufficient resources or the climatic conditions needed to produce enough food to support its population. Therefore, Israel, like a growing number of other countries that are dependent on external resources, relies on imports to meet demand, displacing the environmental impact of meat consumption to other countries. This research utilizes a multi-regional consumption perspective, aiming to measure the carbon and land footprints demanded by Israeli cattle and chicken meat consumption, following both domestic production and imports of inputs and products. The results of this research show that the "virtual land" required for producing meat for consumption in Israel is equivalent to 62% of the geographical area of the country. Moreover, almost 80% of meat consumption is provided by locally produced chicken products but the ecological impact of this source is inconsequential compared to the beef supply chain; beef imports comprise only 13% of meat consumption in Israel but are responsible for 71% of the carbon footprint and 83% of the land footprint. The sources of Israel's meat supply are currently excluded from environmental impact assessments of Israeli processes. However, they constitute a significant fraction of the system's natural capital usage, so they must be included in a comprehensive assessment of Israel's consumption habits. Only then can policy be created for a sustainable food system, and inter-regional sustainability be achieved.

Keywords

Meat Consumption
Sustainable Food Systems
Interregional Sustainability
Carbon Footprint
Land Footprint

Introduction

In recent decades, the international trade of food commodities has become a central means of supplying the needs and wants of billions of consumers all over the world [4] [42]. Food supply chains have grown longer and more intricate, involving stages taking place in multiple regions [40]. In a globalized world with a rapidly increasing population, poor management of natural resources may lead to soil erosion, water shortages, climate change, and pollution, threatening food security in both the developed and developing worlds [11] [54] [60] [62] [67].

For countries with limited bio-capacity where domestic supply is dependent on the global system, national food system sustainability is also reliant on other regions; low yields or ecological damage will not only affect the country of production, but might also dramatically affect countries with roles farther down the commodity chain [40]. Furthermore, as the virtual distance between the source of production and the consumer grows, direct environmental ramifications caused by the production of a commodity become more difficult for the consumer to perceive [40]. Although various academic research studies have explored the biophysical inputs and outputs demanded by food production or processes within a single country (e.g., [5] [19] [24] [72]), a growing number of studies advocate for taking a full-system or consumption-based approach, accounting for activities taking place throughout the entire life cycle (e.g., [10] [13] [14] [15] [16] [35] [39] [40] [48] [51] [56] [57] [58] [59]).

The geographic attributes of the state of Israel, in particular, place heavy limitations on agricultural yields, making the country poorly suited for feeding its rapidly increasing population. Consequently, Israel is dependent on imports from many other countries to support domestic food supply, especially for inputs to the meat system.

This is especially relevant as many studies have found that the global meat system contributes significantly to global natural capital use and greenhouse gas emissions (GHG) (e.g., [23] [46] [47] [50]). To date, very little is known about the global environmental dimension of the Israeli meat system. This study asks what the breadth is of two major biophysical components of the meat system – land resources and emissions of greenhouse gases. It analyzes the state of Israel's meat land and carbon footprints from each foreign and domestic source of supply and explores how local consumption may influence international food security and interregional sustainability.

Background

Global Meat Commodity Chains

The global food system has undergone drastic changes in the past several decades, due in part to the availability of fossil energy, the development and increased use of artificial inputs such as fertilizers and pesticides, and transformations in shipping technologies [4] [18] [28] [42] [53]. At the same time, free-trade agreements and the phasing out of food reserves, along with national food policies

have fostered the increasing interconnectivity and dependency of a country on the global system [3] [29]. All of these transformations have contributed to shaping the current globalized food industry, one where the typical commodity chain traverses multiple continents before reaching the consumer, and consumers have access to the highest variety of products than ever before in human history [1] [12] [41]. Coupled with this expansion, meat has emerged as a primary commodity in the typical diet, where developed countries may fill 70% of their protein consumption with animal-based products, sometimes reaching over 300 grams of meat per person daily [44] [53] [64]). Since 1980, developing countries have nearly doubled their meat intake per capita as a result of growing incomes, urbanization, and shifts in food preferences, and world meat exports have increased exponentially (and are projected to continue climbing) to fill demand [20] [23] [64] [70].

The last four decades have shown an increased adoption of industrialized livestock rearing practices to accommodate growing consumption habits, including higher inputs of fossil fuels, expansion of built structures, and industrialized feed production (replacing conventional pasture-based systems) [2] [44]. Yet these systemic changes hold substantial implications for the environment and the availability of natural resources. The report *Livestock's Long Shadow*, sponsored by the United Nations Food and Agricultural Organization (FAO), estimates the livestock sector as causing 18% of anthropogenic GHG emissions, using 30% of global land resources and 8% of global available water [66]. The FAO recently published a follow up to this report, updating the greenhouse gas burden of the livestock sector as 14.5% of human-induced emissions [28]. Both reports cite the production stages with the greatest impact on natural resources, including animal digestion (CH₄ emissions), decomposition of fertilizers and animal waste (CH₄ and N₂O emissions), burning of fossil fuels to create fertilizers used in feed production (CO₂ emissions), land-use changes for producing feed or grazing (land resources), and land degradation [66]. A growing awareness of the issues involved in meat production has generated different directions to improve productivity in the last few decades, such as increasing the feed conversion efficiency of the animal and an increased prevalence of mixed and landless production systems [2].

Conventional vs. Emerging Approaches to Biophysical Resource Accounting

The conventional approaches of tools to measure the environmental impact of a product, process, or nation include factors attributed only to production, accounting for environmental burdens that take place within the country's borders. These studies also typically measure biophysical inputs and outputs only for a single unit of analysis (i.e. one kilogram of meat), and do not present the total burden for the entire production system (a macro-scale approach). Recently, researchers acknowledge the need to consider a consumption perspective, agreeing that the ecological impact of a product also lies with the individual consumer, or the consuming nation. A growing number of studies advocate the use of a multi-regional consumption approach to measure an individual or a nation's impact on the environment (e.g. [10] [13] [14] [15] [16] [35] [39] [40] [48] [51] [56] [57] [58] [59]).

A small but increasing number of footprint analyses are now taking the consumption approach in analyzing the biophysical resource impacts of a particular country's meat consumption [24] [36] [71] [72].

The carbon and land footprint tools are especially useful for analyzing global commodity chains. These indicators are defined by a consumption-based perspective, serving to track anthropogenic impacts on the environment in the form of greenhouse gas emissions and land resources. This method may be used to measure the impact of individuals, products, processes, sectors, as well as cities, nations, or the world [25].

The carbon footprint is used for calculating greenhouse gas emissions (GHG), formulating a total number comprised of the different types of GHG's that make significant contributions to radiative forcing, namely, carbon dioxide, nitrous oxide, methane, and several fluorinated gases [65]. The land footprint calculates the real land (in hectares) used in each country to sustain a product or process, taking a place-oriented approach as described in [38].

The Israeli Meat System

To date, very little research has used this method to explore Israel's overall food system, and none have studied the national meat system. This is especially relevant as per capita consumption of all meat products in Israel has seen a profound increase in the last two decades, with beef and chicken serving as the two most highly consumed meats, followed by pig meat, mutton, and goat meat [20] [49]. As of 2009, Israel is considered the world's 13th highest per capita consumer of overall meat products, growing from 30.3 kg/person in 1961 to 107.3 kg/person in 2011, an increase of over 250% [20]. Other types of meat represent smaller shares of the overall meat consumption in Israel including (as of 2010) pig meat (2.5 kg/person) and mutton/goat (1.84 kg/person) [20].

Israel's food system is heavily reliant on foreign imports of products and supplemental resources, and while data may show that Israel is self-sufficient in certain products, it most likely does not incorporate the imported materials and energy used to create them (e.g. imported livestock feed). The Israeli beef and chicken supply-chains drastically differ in scale and magnitude; the beef sector is heavily reliant on a considerable number of foreign sources for meat, livestock, and feed while the chicken sector is mainly encompassed within Israeli borders, dependent primarily on external sources of feed. Filling in the gaps from production to consumption along the two distinctive lifecycles, from animal husbandry to slaughter and shipping, would show the true global warming impact and land resources required for Israeli meat consumption, identifying barriers and solutions for achieving food security, interregional sustainability, and building a sustainable food system.

Methods

Our study takes a multi-regional consumption perspective to account for beef and chicken consumption in Israel, documenting domestic sources of production, as well as the import of beef, calves,

and feed. Data sources include national and international databases, interviews with key local officials, analysis of policy documents, and peer-reviewed journal articles. The results represent activities taking place in 2010, following the most recent data available.

The four primary categories considered include: (1) beef import, (2) calf import, (3) domestic beef production, and (4) domestic chicken production. Category 1 includes boneless beef and beef cuts that are imported from several countries, mainly Latin America, Europe, and China. Category 2 follows calves exported to Israel from Australia and Eastern Europe when they are between two and five months old, then fattened in Israeli feedlots until reaching slaughter weight. The cows produced and consumed entirely in Israel (category 3) include pastured cows and calves, culled dairy cows, and calves born in the dairy sector that are fattened in feedlots. Finally, category 4 follows the local broiler system that is almost entirely sourced by domestic poultry production, with negligible import/export quantities of chicken meat or products.

Our analysis encompasses the following stages: a) Calculation of overall meat consumption from each source of supply; b) Measurement of the main sources of greenhouse gas emissions and land resources involved in production from each source; and c) Quantification of GHG emissions related to overseas transport to Israel.

Carbon and Land Footprints

This research estimates the carbon footprint along the full commodity chain of consuming one ton of cattle or chicken meat in Israel, accounting for all burdens resulting from the production and transport of feed, on-farm operations (animal husbandry, fertilizer application, machinery), slaughter, and overseas transport. Results are presented in CO₂ equivalent, using the factors from the IPCC 4th Assessment Report of 1 kg CO₂/kg CO₂, 298 kg N₂O/kg CO₂, and 25 kg CH₄/kg CO₂, [65]. The land resources considered include pastureland and cropland for cattle, and for chickens, cropland and land required for chicken coops ("coop-land"), calculating the actual area of land needed per unit of meat or feed for consumption in Israel. Overseas transportation to Israel was calculated from the nearest port of the source country to Israel using the most direct route. **Table 1** and **Table 3** present the factors and data sources used for each region of analysis.

To accommodate for the multi-functionality of the cow's carcass, we assume that 87% of the value is in the beef carcass, and that the remaining value is in the slaughter fats, offal, and hide (as cited in [9] and [43]). We allocate this percentage to the final results for data related to the beef supply chain, for sources that have not already included this allocation.

Research Limitations

Due to the scope of this study and lack of data availability, certain components of the Israeli meat system are not accounted for in this study. The two sources of meat considered make up the majority of national meat consumption, therefore, other sources of meat

consumption such as turkey, pig, sheep, goat, and other poultry products are not considered. These products are recommended for inclusion in future research on biophysical inputs and outputs of the Israeli meat system.

When specific figures were not available or were unreliable for this study, they were either not considered or assumptions are made. Some omitted components include implications of land-use change for pasture and cropland production, CO₂ emissions and land resources within calf-exporting countries, and transportation occurring within the country post-production, such as from the farm-gate to the port. Additionally, factors estimated for Brazil are used as a proxy for the other Latin American countries considered.

The approach of this research encompasses the impacts directly related to the production of meat for Israeli consumption, by measuring the effect for the actual slaughtered animal. To this degree, emissions and land and water resources related to land-use change and the supporting cow-calf herd are not included. Based on studies that have included the land-use change component, the inclusion of this data may result in an increase between 50 to 100 percent in the footprint [43]. Similarly, the inclusion of the biophysical inputs and

outputs related to the cow-calf herd required to support the cows slaughtered each year would result in a significant increase in each footprint. Footprints are also not considered for culled dairy cows or the production of agricultural residues used in feed, as these would ideally be accounted for in footprint studies of those respective sectors.

Finally, this study's boundaries extend to the production of one ton of beef or chicken, and do not include any subsequent stages in the lifecycle. Further research would be needed to estimate the full carbon and land footprints of consumption from cradle to grave, such as processing into meat products, transportation to vendor and consumer, storage, food preparation, and final waste disposal.

Given that the data used is the most up-to-date and accessible from is the information available, the limitations presented here should not impair the impact of the research. However, we do acknowledge that this study is the first step in evaluating the biophysical impact of Israeli meat consumption and encourage continued refining of the data in the future to present the most accurate and reliable picture of the system.

Table 1: Data factors for beef import

Country	Enteric Fermentation	Manure Management	Feed Production/ Farm Operations	Manure Management	Feed Production	Slaughter	Shipping Distance (km) ^f	Shipping factor	Pasture Land	Cropland (hectares)
	(kg CH ₄ /head) ^a	(kg CH ₄ /head) ^a	(kg CO ₂ /kg carcass weight)	(kg N ₂ O/head) ^a	(kg N ₂ O/kg carcass weight)	(kg CO ₂ /kg carcass weight) ^a		(kg CO ₂ /ton*km) ^g	(kg beef/hectare)	
Argentina	56	1	0.3 ^b	11.91	N/A	0.2	13,505	0.016	46 ^h	N/A
Brazil	56	1	0.3 ^b	13.76	N/A	0.2	9,304	0.016	49 ^h	N/A
China	188	1	4.12 ^c	7.95	1.43 ^e	0.2	12,966	0.016	481	8,340
France	57	7	3.99 ^d	7.9	1.48 ^f	0.2	2,948	0.016	248 ⁱ	4,860 ⁱ
Netherlands	57	6	2.65 ^d	4.5	0.86 ^f	0.2	6,219	0.016	1,189 ⁱ	90 ⁱ
Panama	56	1	0.3 ^b	12.51	N/A	0.2	11,838	0.016	46 ^h	N/A
Paraguay	56	1	0.3 ^b	21.29	N/A	0.2	12,047	0.016	54 ^h	N/A
Poland	58	6	4.98 ^d	5.8	1.32 ^f	0.2	7,599	0.016	359 ^g	6,240 ⁱ
UK	57	6	4.04 ^d	8.98	2.26 ^f	0.2	5,569	0.016	129 ^g	2,000 ⁱ
Uruguay	57	1	0.3 ^b	14.15	N/A	0.2	13,505	0.016	49 ^h	N/A
Rest of the World	57 ^c	3 ^c	4.12 ^c	6.8	1.43 ^c	0.2	N/A	N/A	481 ^c	10,530 ^c

a. [20]; b. [7]; c. Calculated average; d. [43]; e. [63]; f. [55]; g. [17]; h. Calculated data using [6]; i. Calculated data using [43]

Table 2: Data factors for calf import

Region	Enteric Fermentation	Manure Management	Shipping Distance (km) ^c	Shipping factor	Slaughter
	(kg CH ₄ /head) ^a	(kg CH ₄ /head) ^a		(kg CO ₂ /ton*km) ^d	(kg CO ₂ /head) ^e
Australia	53.5 ^b	1.4 ^b	17,050	0.013	69
Eastern Europe	52 ^a	1.8 ^a	2,113	0.7	69

a. Calculated average using factors of Australia and Israel from [20]; b. Calculated average using factors of E. Europe and Israel from [20]; c. [55]; d. [17]; e. Calculated data using [32] and [33]

Table 3: Data factors for domestic production

Region	Enteric Fermentation (kg CH ₄ /head) ^a	Manure Management (kg CH ₄ /head) ^a	Manure Management (N ₂ O) Kg CO ₂ e/kg boneless beef	Slaughter (kg CO ₂ /head)	Pasture Land (Cow-calf/hectare) ^d	Coop Land (hectares/head) ^e
Israel (Chicken)	N/A	0.02	0.55	0.75 ^c	N/A	2.2 x 10 ⁻⁵
Israel (Cattle)	47	1	1.88	69 ^b	2.5	N/A

a. [20]; b. Calculated data using [32] and [33]; c. Calculated data using [32] and [34], 2013; d. [61]; e. [30]

Table 4: Data factors for feed import (calculated data using [38])

Data Factor/Region		North America	Black Sea Region	Europe	Israel	ROW
% of Grain Supply	Wheat	15	60	11	14	N/A
	Maize	63	N/A	N/A	5	32
Nitrogen (Kg N ₂ O/ton)	Wheat	154	101	149	262	N/A
	Maize	104	N/A	N/A	104	104
Fertilizer (Kg CO ₂ /ton)	Wheat	63	79	45	76	N/A
	Maize	32	N/A	N/A	33	32
Machinery (Kg CO ₂ /ton)	Wheat	54	59	32	48	N/A
	Maize	14	N/A	N/A	6	14
Shipping (Kg CO ₂ /ton)	Wheat	57	28	24	N/A	N/A
	Maize	57	N/A	N/A	N/A	57
Land (hectares/ton)	Wheat	0.46	0.4	0.17	0.45	N/A
	Maize	0.11	N/A	N/A	0.06	0.11

Results

Figure 1 presents the distribution of the sources of Israeli meat consumption across the world. This map highlights that the main source of supply is chicken meat, providing 78% of total meat consumption. Imports of beef and calves provide 13 and 4% of consumption, respectively, and domestic sources of beef production contribute 5% (**Figure 1**).

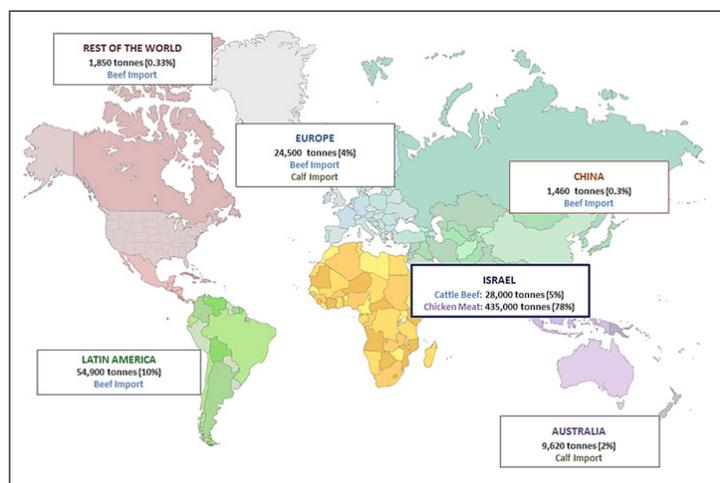


Figure 1: Sources of Israeli Meat Consumption, by Region and Percentage Contribution

Table 4 presents the four main processes contributing to cattle and chicken meat consumption in Israel, and the quantities of consumption from each category in 2010. **Appendix 1** details the specific countries contributing to each category and their overall burden.

Table 5: Israeli meat consumption, by category*

Process	Consumption quantity (kg)	Consumption per capita (kg)	% of Total Meat Consumption
Beef Import	71,150,000	9.6	13
Calf Import	21,200,000	2.9	4
Domestic Beef Production	28,000,000	3.8	5
Domestic Chicken Production	435,000,000	58.6	78
Total	555,350,000	74.9	100

* This table represents local data collected from [34] and [68].

Carbon Footprint

The global warming potential for average Israeli beef consumption in

2010 measures at 2,273,000 tons CO₂e overall and 22 tons CO₂e per ton of beef. Results for chicken meat are 511,000 tons CO₂e overall and 1.2 tons CO₂e per ton of meat. Factors influencing the size of the beef footprint include: the quantities of meat consumed from each region of production, the type of cattle, feed, and energy sources used in each supplying region, and the distance of shipping between the source country and Israel. Relevant components in the chicken meat

footprint are the quantity of consumption, quantity of feed, energy sources, and shipping of feed from overseas. The following figures break down the overall footprint into these considerations, showing the carbon footprint of each meat product by stage of production and shipping, with the share of the total GWP for each source of meat supply (*Figure 2*) and GWP per kg by source (*Figure 3*).

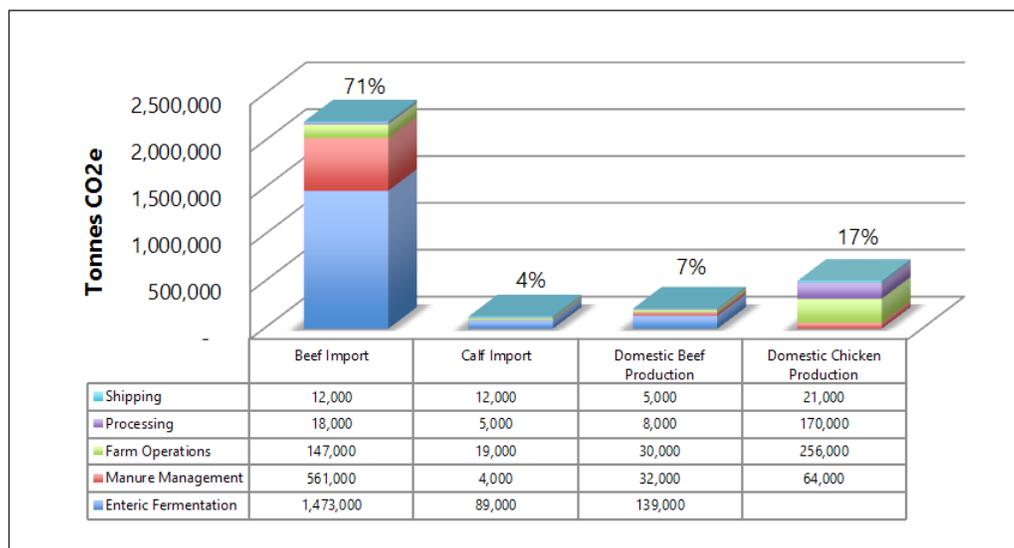


Figure 2: Carbon Footprint, by Stage, Source of Supply, and Share of Burden (kg CO₂e)

The figures show that the majority of the GHG emissions are attributed to beef import (over 2,000,000 tons), through production taking place outside the country, and the most significant process in this category is enteric fermentation. The calf import and domestic beef production categories together account for about 11% of emissions (~345,000 tons).

Compared to the beef system, chicken production holds the highest burden in the categories of shipping, feed production, and slaughter. However, as shown in *Figure 2*, these results are primarily attributed to the high magnitude of local poultry production (220 million chickens slaughtered/year), as this source holds the lowest emissions per kg compared to the other categories considered.

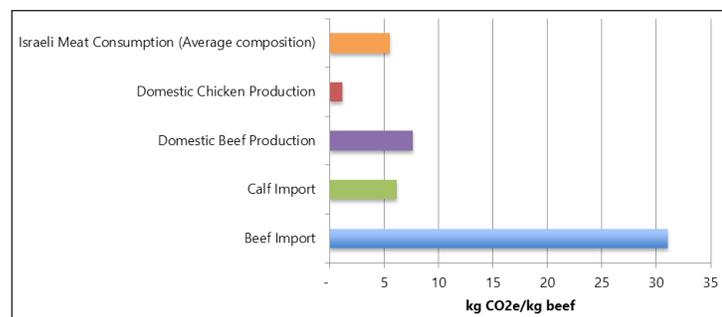


Figure 3: Carbon Footprint per Unit by Source of Supply (kg CO₂e/kg meat)

Land Footprint

The global land footprint for average Israeli beef consumption in 2010 measures 1,150,000 hectares overall and 9.5 hectares per ton of beef, where 96% of the system is pasture-based and the remainder is based on crop-land. Chicken meat consumption requires 200,000 hectares of land, and 0.5 hectares per ton of meat. The key factors impacting the size of the footprint include: the quantities of meat consumed from each region of production (presented in *Table 1* above) and the type and quantity of feed used in each supplying region.

Figure 4 and *Figure 5* break down the overall footprint by source, land-type, and percentage contribution to the footprint. As mentioned above, land sources within calf exporting regions are not considered due to data uncertainty.

Similar to GHG emissions, the greatest burden on the land footprint falls outside of Israel's borders through beef imports, both in total land resources and in hectares per unit. *Figure 4* shows that domestic chicken production requires more hectares than domestic beef production, and uses the greatest amount of cropland compared to the other categories. As the land impact per kg of chicken production presents the lowest results (*Figure 5*), this high burden of cropland is primarily due to the significant levels of chicken meat consumption.

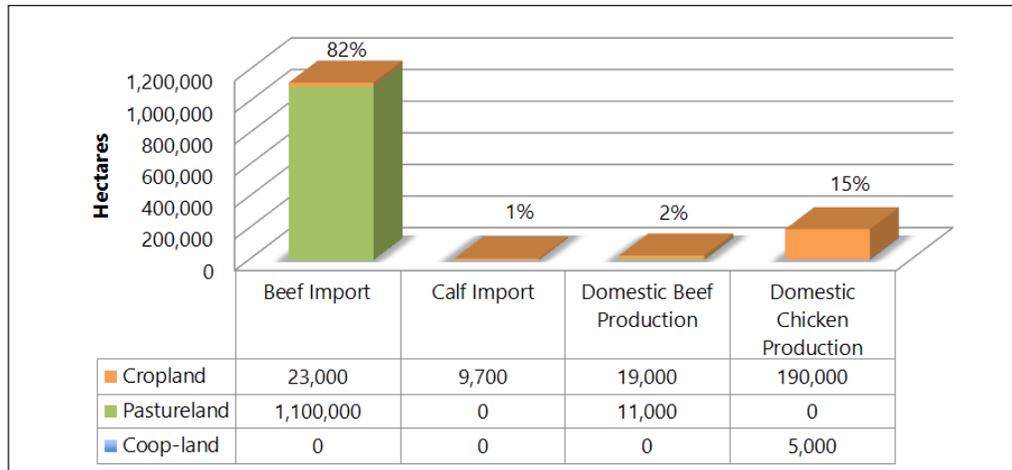


Figure 4: Land Footprint, by Source of Supply, Land Type, and Percentage of Footprint

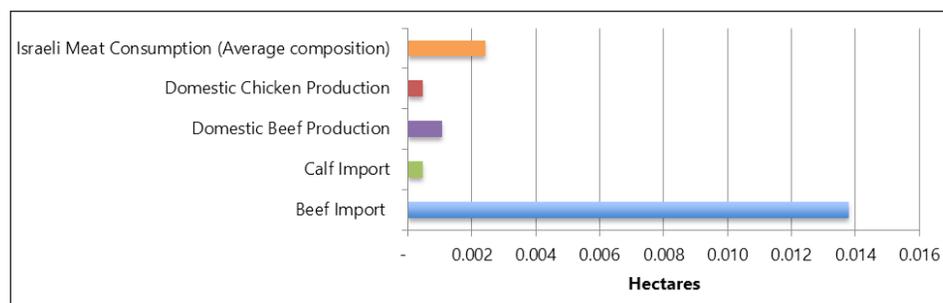


Figure 5: Land Footprint per Unit (hectares/kg), by Source of Supply

Discussion and conclusions

According to 2009 data, Israel is the world's 13th highest per capita consumer of meat products, 18th highest per capita consumer of beef (90,000 tons), and the 5th highest consumer of chicken (nearly 400,000 tons) [20]. Israeli meat consumption, both overall and per capita, has grown significantly in the past several years and has continued to rise since the year analyzed in this research. This study measures the population's burden on the meat system at 410 kg CO₂e emissions per capita, and land area at 0.2 hectares per capita.

While few studies take the same approach as the research presented here, studies focusing on countries with more self-contained production systems present similar results. Research on beef systems includes Peters et al. [52] (Australia beef production- 22,000 kg CO₂e/ton), Leip et al. [43] (Netherlands beef production- 16,400 kg CO₂e/ton; United Kingdom beef production-7.9 hectares/ton), and Cederberg et al. [7] (Brazil beef production- 40,000 kg CO₂e/ton; 25 hectares/ton). Select studies on chicken meat systems include both production and consumption perspectives, such as Mogensen et al. [46] (Denmark chicken production-2,600 kg CO₂/ton; 0.5 hectares/ton), Meier et al. [45] (Germany chicken production and packaging- 0.891 hectares/ton), Williams et al. [73] (United Kingdom chicken production- 0.6 hectares/ton), Williams et al. [74] (Brazil chicken production- 0.4 hectares/ton), Fiala [23] (USA chicken

consumption-1,100 kg CO₂/ton), and Leip et al. [43] (Ireland chicken consumption-1,600 kg CO₂/ton).

The results of this research indicate that although chicken makes up 78% of meat consumption in Israel, it makes a low contribution to the overall carbon and land footprints attributed to Israeli meat consumption. Furthermore, beef imports comprise only 13% of meat consumption in Israel, but are responsible for 71% of the carbon footprint and 83% of the land footprint, with the majority of this impact caused by imports from the pasture-based production system in Latin America. While cattle and poultry meat *production* within Israel requires almost half of the total agricultural land in the country, the virtual land footprint of *consumption* exceeds the total area of Israeli agricultural land by over 150%, the equivalent of more than 60% of the geographical area of the country. This indicates that small increases in beef imports to fill growing consumption habits would likely elevate the already significant carbon and land footprints, a great deal more than a large increase in local chicken production. Furthermore, this study finds that the difference between the local and foreign production systems is significant, whereby if the quantities of the imported meat and local production were switched, the carbon and land footprints would decrease by up to 30 and 50 percent, respectively.

The factors contributing to changes in the system's biophysical

* Converted from m²/kg

resource requirements undergo fluctuations between years, such as the composition of the energy mix used in Israel, more meat being imported from Latin America, or shifts in modes of international transport. Depending on the type of change, the footprints may experience a significant increase or decrease. While certain shifts, such as sources of supply, are driven by purchasing decisions by producers, a consumer's choice of what type of meat to consume can have a significant impact. If Israeli consumers reduced intake of beef by 50% and replaced this quantity with chicken, the carbon and land footprints would decrease by 40% and 41%, respectively.

Countries with limited biophysical resources, such as Israel, have little choice but to import large quantities of food products and source materials if they wish to maintain the population's consumption levels. In light of rising meat consumption habits over the years, Israel has recognized that it is not effectual to expand domestic beef production to supply this demand, whether for reasons of economic considerations or physical limitations. While trade is typically an essential part of allowing countries access to unavailable food products and can be a cost-effective alternative to local manufacturing, the negative implications of Israel's meat system supersede the positive. This study demonstrates that the source of supply for the imported product does matter, especially for meat products, and raises questions about food system sustainability across these supply chains. Israel is essentially importing the bio-capacity from more resourceful regions, yet each source country from which Israel imports has diverse production practices with different effects on natural capital usage. When an exporting country uses cattle-rearing methods that cause resource exploitation, the lines of who is responsible become blurred.

While this research focuses primarily on Israeli consumption patterns, it demonstrates the need to consider interregional sustainability, and contains implications for all countries that have roles at different points along global commodity chains. The analysis encourages Israel and other consumer countries to consider ecological processes occurring in export countries, and to consider their responsibility in the natural capital exploitation in the global industry. While a diversified disaggregated system of many sources of supply may protect Israel in case one region suffers from drought or low yields, the export countries are depleting their natural capital in order for other countries to benefit, threatening interregional sustainability. Moreover, when a source country does experience ecological pressures, it may jeopardize the food systems of all regions that depend on it [40]. While the majority of meat consumption in Israel is not attributed to beef imports, it is not the only country to benefit from beef products produced in the sources evaluated in this study; the regions of supply considered in this research are among the greatest beef exporters in the world. An analysis of the greenhouse gas and land efficiency of the global beef import network would most likely reveal a system where the negative externalities exceed the economic benefits. However, there exists potential to turn these into positive environmental outcomes; under proper management of the commodity chain, the existing network can be used to source production from regions that are more environmentally efficient.

As illustrated by this research, the trans-boundary implications of Israeli meat consumption cannot be ignored, and will continue to grow in magnitude until they are addressed. Considering the consumption side of global food systems, such as the contribution of Israel to the global meat commodity chain, is a necessary exercise in learning to live within our ecological limits and is the first step to achieving a global sustainable food system.

Appendix

Appendix 1: Makeup of Israeli meat consumption, by region

	Regions Considered (% of source)	Data Sources
Beef Import	Latin America (77%)	[6] [7] [20]
	Europe (18%)	[7] [43]
	Asia (2%)	[7]
	Rest of the World (3%)	[7] [20]
Calf Import	Australia (45%)	[20] [26] [68] [69]
	Europe (55%)	[20] [26] [68] [69]
Domestic Beef Production	Israel (100%)	[8] [21] [26] [32] [38] [61] [68] [69]
Domestic Chicken Production	Israel (100%)	[8] [22] [30] [33] [38]

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