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Global diet not likely to become carnivorous as animal-source calorie consumption shares and human trophic levels stabilize in the long run

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We investigate the hypothesis that the global human diet will become carnivorous in the future. A long-term view of the development of global animal-source calorie consumption shares and human trophic levels is presented based on FAO food balance sheet and World Bank data. Our results show that across an analytically constructed period of 248 years both measures have stagnated in high-income countries since around 1985. Our findings imply that global food consumption patterns are not likely to endlessly increase the environmental burden associated with animal agriculture.

KEYWORDS

animal-source products, diet sustainability, global food consumption patterns, human trophic level, long-term development

1 Introduction

Income is a key driver of consumption expenditure (Muhammad et al., 2017). As people become more affluent, they tend to allocate proportionally more income to non-food items, thereby reducing the share spent on food and thus mirroring a behavior known as Engel's Law (Choi and Lee, 2019). Moreover, at low-income levels, consumers typically dedicate a significant share of their food expenditures to carbohydrate-rich staples such as rice or bread. As their incomes rise, starchy staples tend to be replaced by protein and micronutrient-rich foods such as meat and fruits. This shift, rooted in empirical observations across diverse societies and historical contexts, is known as Bennett's law (Bennett, 1941; FAO et al., 2023, p. 73).

Here we investigate visually and statistically the development of the global diet composition across a long period using the share of animal-source calories (ASC) (mainly derived from meat, milk, eggs, fish) in total calorie intake as well as human trophic levels (HTL) and their relationship to per capita income levels.

HTL measures the energy intensity of diet composition and reflects the relative amounts of plant-based as opposed to animal-source products in the human diet. Higher HTL values indicate a diet richer in energy-intensive animal products. The current global HTL average of the human diet is about 2.2, which reflects an omnivorous diet. Higher HTL values (above 2.5) indicate a carnivorous diet, while lower values (~2.0) suggest plant-based (vegetarian or vegan) diets (Bonhommeau et al., 2013).

Trophic levels provide insights into the ecological footprints of diverse dietary patterns, energy efficiency, and resource utilization (Charles, 1950; Begon et al., 2006). The greenhouse gas emissions per unit of energy which result from the production of

animal-source foods are often higher than that of plant-based foods because caloric energy is lost at each trophic level (Godfray et al., 2018). Nevertheless, eating is not only about calorie consumption. Animal-source products provide other macro- and micronutrients such as essential amino acids and various vitamins and minerals (e.g., calcium, zinc, iron, vit. B12).

2 Empirical approaches

For the creation of a long-term view of global ASC and HTL developments we combined Food Balance Sheet (FBS) data from the Food and Agriculture Organization (FAO, 2019) and real GDP (constant 2015 US\$) data from the World Bank between 1961 and 2022. We used the World Bank's categorisation of income groups (low, lower middle, upper middle, and high) which are based on gross national income (GNI) per capita (World Bank, n.d.).

By displaying the 62-year developments of the four income groups next to each other, a unique 248-year long-term view was constructed. We propose that different income level groups reflect different economic development stages and thus time intervals. Hence, by displaying subsequent income level groups next to each other a long-term view into the past can be created. However, the validity of this approach rests on the assumption that dietary transition pathways are broadly comparable across the countries analysed. Given a potential heterogeneity in cultural, institutional, demographic and agroecological conditions, this assumption may only partially be met. Accordingly, this reconstruction should be interpreted as an analytical construct rather than a literal historical trajectory and may entail limitations and sources of bias.

To calculate extended time series of global ASC and HTL scores, we needed to address a structural break in the FBS data series caused by a 2020 change in methodology. We combined the 1961–2013 and 2010–2022 series (the most recent available year) into one dataset. For this, we followed the treatment suggested by Vonderschmidt et al. (2024).

In a second step, we used approximation techniques such as polynomial regression and locally estimated scatterplot smoothing (LOESS) moving averages to remove short-term fluctuations. These graphs visualize the underlying trends more clearly.

To estimate the HTL values used for our study period, we followed the guide and protocol designed by Bonhommeau et al. (2013).

HTL is the weighted mean of the trophic levels of all food items consumed by the population/individual. We used Equations 1, 2, and FBS data to obtain HTL values.

$$\text{HTL} = 1 + \frac{\sum_i Q_i \times \text{TL}_i}{\sum_i Q_i} \quad (1)$$

Q_i is the quantity (in kilograms) of food item i consumed, and TL_i is the trophic level of food item i . The TL of each food item derived from all the plant species and detritus is assumed to be 1, i.e., the producers. Other food species' trophic levels are taken from the literature, i.e., two in herbivores and detritivores (first-level consumers) and three in second-level consumers.

$$\text{TL}_i = 1 + \sum_j \text{DC}_{ij} \times \text{TL}_j \quad (2)$$

However, omnivorous consumers usually have trophic levels with non-integer values. In this case, DC_{ij} represents the fraction of food item j in the diet of predator i . Therefore, the trophic levels of most fish and other seafood are between 2.0 and 5.5.

The polynomial regression and LOESS moving average values were estimated using RStudio R3.6.0+.

To validate our findings, we conducted econometric fixed-effect panel data regression (Hsiao, 2003) to estimate the association of per capita GDP with ASC and HTL over the study period using StataSE 18. Unlike regular time-series or cross-section regression, panel data have double subscripts on their variables, i.e., t for year, and i denoting in our case countries (Hsiao, 2003). The regression model takes the following form (Equation 3):

$$y_{it} = \alpha_i + X_{it}\beta + u_{it} \quad (3)$$

$$i = 1, \dots, n; t = 1, \dots, T.$$

y_{it} is the outcome variable which is HTL or ASC (for country i at year t).

α_i is the unobserved time-invariant individual effect for each country i (n country-specific intercepts).

x_{it} is real per capita GDP (the only predictor variable we use).

u_{it} is the error term.

To improve the skewness, normality, homoscedasticity and linearity properties of our data and facilitate the interpretation of the regression estimates, natural logarithms model specifications were used (Greene, 2018).

3 Results

The ASC and HTL variables are statistically highly significant and positively associated with each other with little difference across the income groups. A panel regression of $\ln\text{ASC}$ on $\ln\text{HTL}$ yields R -squared values of 0.76 (low income), 0.79 (lower middle income), 0.88 (upper middle income) and 0.83 (high income).

The obtained evolution patterns of the ASC and HTL reveal decreasing consumption when either using polynomial regression or moving averages. Our results Figures 1a,b indicate that ASC has not grown significantly over the last forty years or so in high-income countries. The HTL results, as shown in Figures 1c,d, are similar to the ASC ones.

The income group membership of several countries changed during the 62-year study period (World Bank, n.d.). Because some national diets may not significantly alter when moving from one income group to another, the decline in consumption in the high-income group may be due to the change in its country composition. We tested the robustness of our findings by calculating the results only for countries that did not change income groups over the period of investigation. These results can be obtained from the authors upon request. The overall outcome situation remains unchanged with high-income countries' ASC declining after the 1980s peak and HTL stabilizing during the last 40 years or so. For global perspective reasons, we continue with the results of the all-countries dataset.

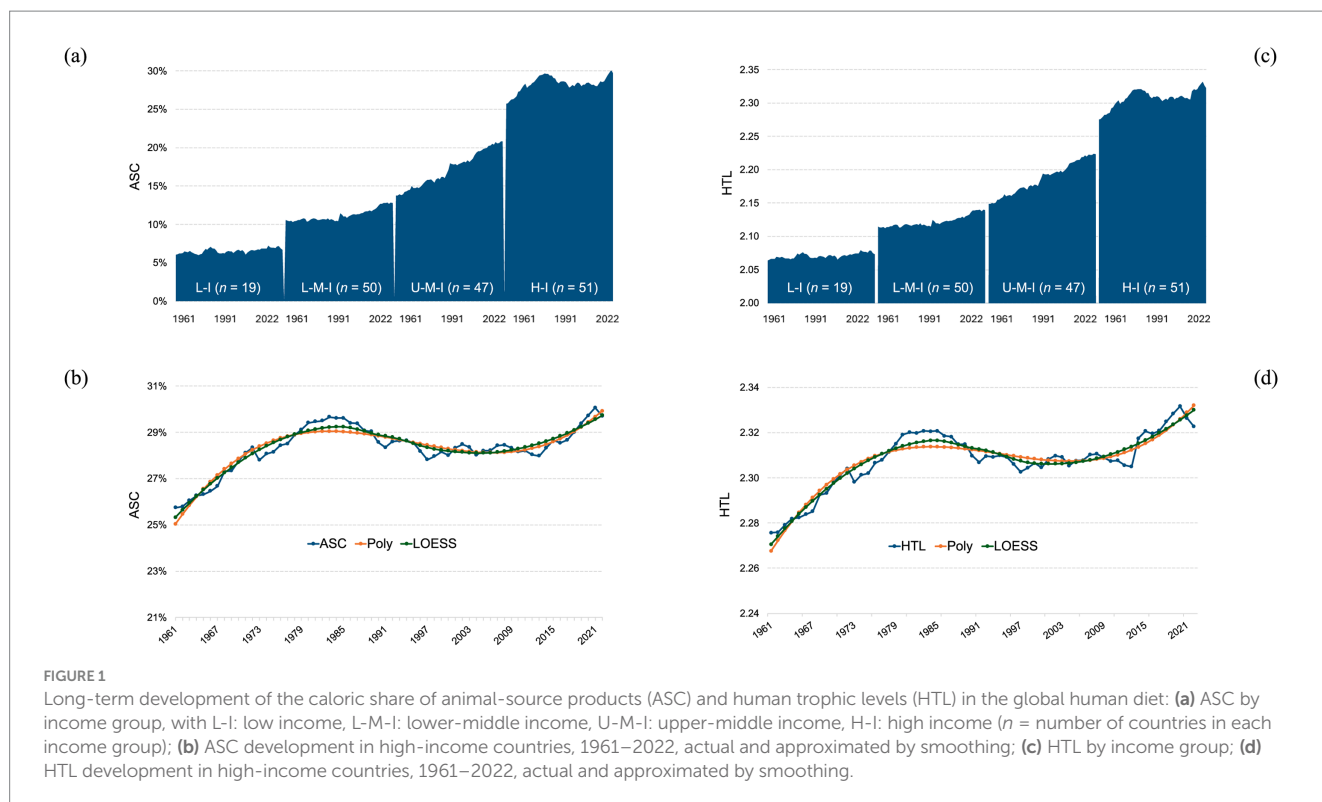


Table 1 shows the strength of the statistical relationship between income and ASC as well as HTL across the different income groups each over 62 years. The regression coefficients (β) and related statistics reveal a consistent and highly significant positive association with income. These effects are strongest for upper-middle-income countries ($R^2 = 0.35$ for ASC and 0.33 for HTL) as well as lower-middle-income countries (0.25 and 0.16, respectively), and weakest for low-income countries (0.05 and 0.01) as well as high-income countries (0.20 and 0.13).

The results indicate that over time animal-source calorie consumption grows in middle-income and partly in high-income countries where ASC and HTL increase. Per capita income explains a significant proportion of this. In low-income countries, both ASC and HTL did not change significantly over the analysed period. Therefore, changes in per capita income explain only a small part of this. In high-income countries, however, both ASC and HTL increased strongly until the mid-1980s. After this period, the associations between per capita income and ASC and HTL were weak.

4 Discussion

Our results align with previous nutritional transition studies, which show a stabilization of meat consumption over time (Godfray et al., 2018; Whitton et al., 2021; Drewnowski, 2024). However, our results provide a new long-term view examining ASC and HTL simultaneously.

The stabilization of ASC and HTL in high-income countries imply that beyond a certain income level, global food consumption patterns are not likely to further increase the environmental burden such as through the overutilization of resources and energy consumption

inefficiency associated with animal agriculture. Drewnowski (2024) proposes a meat consumption-peaking income threshold of approximately \$40,000. However, this value may differ across countries and will change over time.

The important insight from our analysis is that, on historic and current trends, ASC is not likely to grow much beyond a global average ASC value of 30%. This level is in line with the recommendation for a modified EAT-Lancet planetary health diet of a total calorie share of 27% of animal-source calories to “achieve micronutrient adequacy (without fortification or supplementation) for adults” (Beal et al., 2023, p. e233).

As to HTL scores, while the global average value has increased during the last decades, our results show that it may never reach 2.5 (the starting point of carnivorous diets).

However, more data (e.g., population growth) and modelling is needed to quantify the development of total animal-source calorie consumption in the medium-term future. Almost 100 out of the 167 countries belong to the middle-income group. Therefore, most of the global population in the future is likely to increase ASC until a saturation point is reached after sufficiently high incomes are earned. Hence, total global animal-source calorie consumption may still increase for many years. However, our results indicate that at some time in the future when most humans earn adequate incomes, total global animal-source calorie consumption will peak.

While a detailed analysis of regional animal calorie consumption developments is beyond the scope of this article, the newest OECD-FAO Agricultural Outlook offers some medium-term insights (OECD/FAO, 2025). For instance, global poultry, sheep meat, beef, and pig meat consumption is projected to grow by about 21, 16, 13 and 5%, respectively, between 2022–24 and 2034 (ibid). Due to rapid population and income growth, almost half of global consumption

TABLE 1 Panel regression estimates of the strength of the association between per capita income (ln transformed) and diet indicators by country income groups.

Income group (number of observations)	Share of animal source calories (lnASC)			Human trophic levels (lnHTL)		
	R-squared (within)	Coefficient (lnGDP)	Constant (intercept)	R-squared (within)	Coefficient (lnGDP)	Constant (intercept)
High (2,648)	0.1973	0.1711***	-3.0036***	0.1282	0.0134***	0.7033***
Upper middle (2,360)	0.3485	0.2527***	-3.9150***	0.3300	0.0201***	0.6155***
Lower middle (2,695)	0.2492	0.2681***	-4.3120***	0.1642	0.0139***	0.6503***
Low (1,009)	0.0494	0.1548***	-3.8473***	0.0146	0.0030***	0.7081***

*** = statistically significant at $p < 0.01$.

growth will be in upper-middle-income countries. In addition to China and India due to their vast populations, meat consumption growth is expected to be highest in Brazil, Indonesia, the Philippines and Viet Nam. Africa will see a substantial 33% increase in meat consumption during the mentioned period (OECD/FAO, 2025). On a per capita basis, total meat consumption is projected to be just 3% higher in 2034 as compared to 2022–24. This is about half the growth witnessed in the previous decade due to the slowing of per capita meat consumption in most high-income countries (OECD/FAO, 2025).

Finally, our analysis focuses on changes in dietary composition as a function of economic development, proxied by per capita income. Although income is a well-established determinant of diet, consistent with Engel's and Bennett's laws, dietary outcomes are also influenced by additional factors such as urbanisation, demographic structure, relative food prices, public policy, nutritional education and cultural preferences that have not been explicitly included here. The omission of these factors constrains the causal interpretation of our results. Future work could extend this framework by incorporating such complementary drivers, thereby strengthening its conceptual scope and reducing the risk of too deterministic interpretations of the income–diet relationship.

5 Conclusion

Our findings, despite reflecting potential methodological limitations, carry implications for policymaking and nutrition practice. In evidence-based strategies to promote healthier eating habits, nutritionists, researchers and public health officials can design more effective interventions when the relationship between diet and environmental outcomes is better understood.

Greenhouse gas emissions from animal-source foods have been shown to vary widely due to production factors such as feed efficiency, land use and livestock excrement management practices (Poore and Nemecek, 2018; FAO, 2023). This reality provides significant reduction potentials by a more widespread adoption of best livestock husbandry practices. Moreover, technological progress may enable a further reduction of ruminant methane gas emissions by up to 20% through improved animal and feed management, diet formulation and rumen manipulation (Arndt et al., 2022). Therefore, a medium-term transition towards low-carbon livestock (FAO, 2019) seems feasible.

Since ASC consumption is set to stabilize in the future, policymakers should focus on decarbonising livestock production rather than regulating food consumption, a strategy which is often difficult to implement successfully in democratic societies (e.g., Vallgård et al., 2015).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

BK: Data curation, Formal analysis, Investigation, Software, Visualization, Writing – original draft. ER: Supervision, Validation, Writing – review & editing. CF: Conceptualization, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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