Transitioning to healthy and sustainable diets has high environmental and affordability trade-offs for developing countries

Zhen Wang
sinoo@mail.hzau.edu.cn

College of Resources and Environment, Huazhong Agricultural University
https://orcid.org/0000-0002-7902-4093

Zhongci Deng
https://orcid.org/0000-0002-1080-4569

Yuanchao Hu
Wuhan University
https://orcid.org/0000-0002-1965-5395

Cai Li
Huazhong Agricultural University

Jingyu Wang
Huazhong Agricultural University

Pan He
Tsinghua University

Brett Bryan
Deakin University
https://orcid.org/0000-0003-4834-5641

Article

Keywords:

Posted Date: August 29th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3278140/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: There is NO Competing Interest.
Abstract

While dietary transitions offer benefits for both people and the environment globally, uncertainties persist regarding their impacts on the environment, human health, and food affordability across countries and over time. Here, we project water use, dietary quality, and food affordability from 2020–2100 under four healthy dietary scenarios and a baseline to assess potential challenges and opportunities at the country level over time. Using the MAgPIE model, we show that transitioning to healthy and sustainable diets could yield substantial enhancements in global dietary quality. However, in the initial phases, these transitions entail addressing water use and food affordability challenges. Yet, the advantages of transitions will manifest as the population and economy expand. By 2100, average dietary quality and food affordability could improve by 38.48% and 39.95%, and reduce water use by 10.82% globally. Nevertheless, we emphasize that sustainable development will be impeded in developing countries due to increased food demand, with a maximum deterioration in water use and food affordability of 2.54% and 29.25%, respectively. Although negative impacts will gradually subside as the dietary transition is completed, targeted interventions are still needed to improve water management and mitigate potential economic burdens during the dietary transition.

Main

Dietary patterns have a major impact on the sustainability of the global food system and are closely linked to critical issues such as water scarcity and nutritional health. Currently, the food system accounts for approximately 70% of global freshwater withdrawals, posing significant challenges for sustainable water resources management. Meanwhile, unhealthy diets lead to malnutrition, obesity, and other dietary-related illnesses. To address these challenges and promote environmental sustainability, a global transition to healthy and sustainable diets is essential. Studies have shown that adopting a healthier diet in developed countries can curb food demand while promoting environmental sustainability. However, achieving healthy and sustainable diets in low-income countries, particularly in Africa, may require significantly higher food consumption. This, in turn, can increase water use and GHG emissions and decreasing affordability as a major barrier to dietary transitions in developing countries.

Existing studies mainly focus on the benefits of dietary transition at regional or global scales. For example, Springmann et al. noted that reducing animal-based food consumption would reduce the global mortality rate by 6–10% and reduce GHG emissions from the Agriculture, Forestry, and Other Land Use (AFOLU) sector by 29–70%. Himics et al. used a partial equilibrium model and a regional atmospheric chemistry model to show that adopting a flexitarian diet would reduce agricultural ammonia emissions in Europe by about one-third and reduce air quality-related premature deaths by 3% or more in most countries. However, these findings rely on single-region and/or highly aggregated results, without considering national heterogeneity and potential challenges and opportunities presented during dietary transitions. As a result, the inequalities between countries from global dietary transition are overlooked.
In parallel, the changes in affordability associated with a transition to the EAT-Lancet diet have been assessed based on historical food price data\textsuperscript{13,16,17}. Current studies conclude that the transition increased the cost of food, making it unaffordable for at least 1.6 billion people worldwide. Dietary transitions will alter the balance between food supply and demand, leading to price volatility as global production adjusts to changing demand\textsuperscript{20}. While providing implications for food affordability, current understandings on changes in food affordability resulting from adjustments in demand are limited. Recently, Gatto et al. used a global integrated assessment model to assess the partial transition towards the EAT-Lancet diet by 2030, identifying the benefits and trade-offs that arise from changing diets\textsuperscript{21}. Springmann et al. also explored the impact of different vegetarian diets on food affordability using an integrated assessment model earlier\textsuperscript{22}. However, these findings focused solely on comparing the impact and benefits of dietary transitions at the endpoint without considering dynamics over time and/or differences between various dietary patterns. In addition, the magnitude of the impact of the transition on dietary quality is still lacking\textsuperscript{19}. Considering that countries have different diet preferences, exploring and comparing the effect of diverse dietary patterns on the environment, dietary quality, and food affordability is crucial.

In this study, we evaluated the dynamic changes related to environmental sustainability, associated dietary quality, and food affordability. We used a spatially explicit, recursive dynamic land-use optimization model—the Model of Agricultural Production and its Impacts on the Environment (MAgPIE) (version 4.6.3)\textsuperscript{23}, which enable the evaluation of dynamic changes over the period 2020–2100. Based on the quantification, we explored the potential integrated benefits of adopting different healthy and sustainable diets at the country level over time. These dynamic results can provide further insight into the environmental and economic challenges that different countries may face in the dietary transition process, as well as the enduring benefits that can be accrued upon the completion of this transformation. We underscore that while dietary transformation can reduce water use and improve diet quality and food affordability globally, developing countries must prepare for the potential escalation in water use and economic burden necessitating thoughtful reflection in their decision-making. This could require certain measures of international governance and support. This knowledge can assist countries in actively promoting a dietary transition and working towards achieving Sustainable Development Goals.

## Results

### Changes in water use due to dietary transitions

Our study investigated the impact of different dietary scenarios on global water use from 2020 to 2100, including the baseline scenario (BaU), the EAT-Lancet diet (EAT), dietary guidelines for Americans (HUS), the Mediterranean (MED) and the vegetarian (VEG). In the BaU scenario, water use was projected to increase from 4448.13 km\textsuperscript{3} year\textsuperscript{−1} in 2020 to a peak of 5203.03 km\textsuperscript{3} year\textsuperscript{−1} in 2070 before declining to 4741.11 km\textsuperscript{3} year\textsuperscript{−1} by 2100 (Fig. 1a). Water use in 127 countries by 2100 exceeded its 2020 level (Fig. 1b), with notable increases in Argentina, Brazil, Chad, Mexico, and Uruguay (Figure S3). The region
with the largest projected increase in water use was Argentina (137.33 km$^3$ year$^{-1}$). Conversely, with fewer changes in irrigated areas and constant water use efficiency, 51 countries were projected to use less water because of declining populations later in the century (Figure S4). India was expected to experience the largest reduction, with a decrease of 520.34 km$^3$ year$^{-1}$. Under four dietary transition scenarios, reducing animal-based food demand led to a projected decrease in global water use to a range of 3893.06-4505.38 km$^3$ year$^{-1}$ by 2100, in which VEG and EAT biased towards plant-based diets can significantly reduce water use, while MED and HUS diets were relatively less effective in reducing water use. Moreover, we observed a period of upward trends in global water use (except for the VEG scenario) due to higher food consumption. Among them, the HUS and MED diets were the most significant, and the water use peaks would be reached in 2060 (5072.13 km$^3$ year$^{-1}$) and 2065 (4941.87 km$^3$ year$^{-1}$), respectively (Fig. 1a).

Some African and Asian countries experienced water use challenges due to higher food consumption during the early stages of the transition (Fig. 1c-n). For example, in the EAT scenario, reducing water-intensive foods lowered water use for sugar, animal products, and feed. However, many African and Asian countries initially faced water use challenges due to higher food consumption. By 2030, 52 countries exceeded the BaU scenario in water use. Vietnam was projected to have the largest increase (39.40 km$^3$ year$^{-1}$) due to increased cereal and fruit consumption. While water use gradually decreased with the dietary transition, it remained higher than the BaU scenario. Côte d'Ivoire and Laos also faced similar challenges, increasing by more than 5 km$^3$ year$^{-1}$ each.

Under the HUS and MED scenarios, more countries (80 and 66, respectively) experienced increased water use compared to the EAT scenarios in 2030. The higher consumption of water-intensive products, particularly meat and sugar, contributed to this trend. Consequently, approximately 34% of countries faced more severe water use challenges. Despite reaching peak water use by 2080 in 50% of these countries, water use continued to increase in 23 countries due to higher food consumption. In contrast, the VEG scenarios substantially reduced water use by reducing meat consumption. This transition to a plant-based diet greatly conserved water resource. However, increased consumption of foods like legumes/nuts$^{14}$ in certain poorer regions may still pose water use challenges.

**Dietary quality of different dietary scenarios**

With sustained economic growth, the consumption of meat and sugar products was expected to rise in future diets, leading to a continued decline in diet quality globally. In the BaU scenario, global dietary quality was projected to experience a decline from 52.34 in 2020 to 51.36 in 2100 (Fig. 2a). Notably, the decline in dietary quality could be observed in 102 countries, where increased meat and sugar products (-1.42) and decreased consumption of cereals (-2.39) offset the health benefits of certain food categories such as vegetables (+ 0.26), fruits (+ 0.42), seafood (+ 1.40), and that of nutrition indicator like PUFAs (+ 0.97). Consequently, the total Alternative Healthy Eating Index (AHEI) score of these countries was predicted to decrease by $2.69 \pm 2.34$ points (Fig. 2b,c). Additionally, this phenomenon was more
pronounced in economically underdeveloped regions, specifically Africa (-2.64 ± 1.95), Latin America (-3.14 ± 2.25), and Asia (-3.78 ± 3.27), and these regions were expected to have a greater number of countries experiencing a decline in dietary quality, with 26, 22, and 20 countries, respectively.

In all four healthy and sustainable diet scenarios, varying degrees of improvement in dietary quality were observed and remained constant after the completion of the dietary transitions in 2050. The HUS diets exhibited the least improvement, with a score that increased from 52.34 in 2020 to 67.17 in 2050 (Fig. 2a). The MED scenario, with lower sugar and oil consumption, led to an additional 1.08-point improvement compared to the HUS scenario. The EAT scenario further reduced the consumption of dairy products, sugars, and meat while increasing the consumption of legumes/nuts and grains, bringing the total score to 78.12 in 2100. Moreover, the VEG scenario replaced all meat with legumes/nuts and showed further improvements in red meat and slightly higher scores for PUFAs and trans fats. Nevertheless, the lack of seafood/fish consumption results in a lower score of 70.97 in 2100.

Although dietary transitions had the potential to positively impact dietary quality in all countries, the impact was more pronounced in developed countries. Nonetheless, the gap in benefits between developing and developed countries was smaller when meat and sugar consumption is lower. For example, the VEG scenario had the smallest gap of 2.50, while the MED scenario had the largest gap of 4.08. Overall, countries such as Hungary (with scores ranging from 29.76 to 40.84), Slovakia (29.33–39.28), Bolivia (30.22–41.65), Argentina (30.35–40.46), and Switzerland (30.85–41.09) were expected to see the greatest improvement in dietary quality among the four scenarios. This improvement was largely due to the effect of food subcategories on PUFAs and trans fat, indicating that reducing certain food categories and including healthier alternatives could significantly improve the nutritional profile of diets in these countries.

### Share of food expenditure

The share of food expenditure is determined by supply and demand balance, food prices and income. In the BaU scenario, food demand and prices were projected to consistently rise by 15.02% and 24.32%, respectively, with a notable rise in animal-based food expenditure by 68.91% in 2100 (Figure S5). In the HUS and MED scenarios, despite lower overall demand, food expenditure would increase due to higher demand for animal-based products and fruits/vegetables. Food prices were projected to increase by 5.76% and 12.77%, respectively. In contrast, in the EAT and VEG scenarios, the opposite effect was projected, as dietary changes would lead to a much larger reduction in demand for animal-based products. As a result, food prices were expected to fall by -25.96% and -54.36%, respectively.

The share of food expenditure in relation to total income decreased across all scenarios at the global level as the economy developed. This indicates an improvement in global food affordability, with the share decreasing from 1.07–0.35% for each scenario (Fig. 3a), promoting positive prospects for food security worldwide. Nevertheless, there was significant variability in food affordability among countries due to disparities in economic development (Fig. 3c). In 2020, Africa and Asia faced substantial
challenges in food affordability, with the top 20 countries in these regions having an average food expenditure share of 21.69%. The Central African Republic had the highest share at 52.43% in this region. In contrast, developed regions like the US and Europe had negligible affordability issues, with food expenditure shares at 1.22% and 1.49%, respectively. In the BaU scenario, food affordability ranged from 0.34–11.80% for each country, influenced by their economic development. Africa and Asia were projected to experience significant improvements in food affordability by 2100, with a decrease of 13.87% in Africa and 5.20% in Asia (Fig. 3d).

During the dietary transition certain countries, particularly those already facing poverty and economic challenges, encountered increased pressure on food affordability. For example, in 2030, during the transition to the EAT, HUS, MED, and VEG scenarios, 67, 94, 100, and 28 countries, respectively, were projected to face increased food affordability pressure (Fig. 3e), mainly in Africa and Asia. However, this pressure gradually diminished as dietary transitions completed. By 2100, in the MED scenario, only 19 countries experienced a higher share of food expenditure due to increased dietary demand, ranging from 6.32–48.31%, with Iraq being the highest.

Environmental-health-affordability trade-offs and synergies

Finally, we analyzed the synergies and trade-offs associated with different dietary transitions (see method). The results indicated that these transitions can significantly improve global dietary quality over time. However, they also came with trade-offs in food affordability and water use, especially in developing countries (Fig. 4). Among the different diets studied, the HUS and MED diets faced more prominent challenges. In the early stages of dietary transition, both the HUS and MED diets fell into quadrant III, indicating trade-offs between water use and food affordability. Despite the initial challenges, there were positive prospects for dietary transitions. As the transition progressed and was completed (post-2050), the advantages became more evident, with reduced calorie requirements and changing trade-offs shifting towards synergies between food affordability and water use, especially in the HUS and MED diets. Both diets gradually moved from food affordability and water use trade-offs quadrant to triple win quadrant.

It is important to note that the synergies and trade-offs of dietary transitions varied significantly between countries. We highlighted the challenges and potential benefits for different countries before and after the transitions. Due to space limitations, we focused on the dynamic changes of the EAT diet (Fig. 5), and the rest of the diet scenarios are provided in the appendix (Figure S6). In 2030, the adoption of the EAT scenario could have improved dietary quality, reduced water use, and lowered food expenditure in 82 countries by 2030 (quadrant I), but these countries were mainly in developed countries such as Europe or North America (Fig. 5a-b). During the early stages of the transition, many countries in Africa and Asia faced trade-offs in water use (quadrant IV), affordability (quadrant II), or both (quadrant III), despite the improved dietary quality. Specifically, 42 countries encountered food affordability trade-offs, primarily in Africa (-39.55 ± 30.33%), Latin America (-20.47 ± 18.56%), and Asia (-7.33 ± 2.99%). Notably, Burundi, the Democratic Republic of the Congo, and Malawi experienced the most significant declines by -132.28%,
-105.17%, and −66.69%, respectively. Additionally, 27 countries, predominantly in Asia and Africa, faced water use trade-offs (-21.99 ± 21.11%). However, as the dietary transition progressed and reached completion, the trade-offs were expected to gradually ameliorate, with the number of countries facing trade-offs decreasing from 92 in 2030 to 65 in 2050, and to 34 in 2100 (Fig. 5c-e). This was mainly because economic development and population growth would further drive the total food demand in different countries over time without dietary transitions intervention, thereby gradually widening the gap with the total food demand in the diet scenarios (Figure S7). Encouragingly, a significant majority of countries in the EAT scenario are poised to transition to quadrant I before 2060. However, 34 countries were still projected to face water use trade-offs, and 17 of these countries, mainly in Africa and Asia, encountered water trade-offs after the completion of the dietary transition.

Discussion

In this paper, we utilized a global dynamic agro-economic model and detailed food consumption data to establish healthy and sustainable diets for 176 countries to examine the environmental, economic, and health implications of different dietary transitions. Our results revealed that different dietary transitions can reduce water use and improve dietary quality and food affordability globally, but with significant differences across countries. Overall, during the transition phase of the dietary transitions (2020–2050), developed countries will use less water due to reduced dietary requirements and animal-based product consumption, but developing countries, especially some Asian and African countries, may face greater water scarcity. This is mainly due to the large intake gap between these countries and the differences in the intake structure between the original and healthy and sustainable diets, which make these countries need more food demand. Therefore, in the process of global dietary transitions, it is necessary to consider regional equality issues and provide technical support and financial assistance to address the economic and environmental challenges faced by developing countries. Only through this may different countries successfully implement dietary transitions. Moreover, the current unsustainable water use exceeds planetary boundaries (Figure S8) and relying solely on dietary transitions will not be sufficient to achieve sustainable water use within these boundaries. Therefore, it is imperative to implement additional measures, such as enhancing water use efficiency, reducing food waste, and optimizing irrigated cropland areas.

While all countries will eventually benefit from dietary transitions in terms of health, the cost to achieve the same benefits varies. Developed countries can achieve more significant improvements in dietary quality at a relatively lower economic cost (affordability) whereas developing countries experience the opposite. It should be noted that the dietary transitions will lead to greater affordability burdens for some African and Asian countries. Higher food expenditures and slower economic development may hinder and reduce the benefits of global dietary transitions. Although we emphasize that this situation will ease as the dietary transition is completed, policies that support income growth or food price stabilization in these countries during the transition may help to alleviate affordability pressures. This could include measures such as income support programs, subsidies for healthy foods, or price controls on certain
foods. Such policies could have positive long-term effects on both public health and economic development by promoting sustainable and healthy dietary while ensuring affordability. Similarly, our findings indicate that developed and developing countries arrive at the same conclusion in terms of synergies and trade-offs. These findings underscore regional inequalities in dietary transitions, calling for corresponding financial and technical support to narrow the disparities between regions.

We also found significant variations in the impacts of different dietary patterns. The VEG diet improved food affordability and water use, despite some compromises for certain nutrients. The EAT diet achieved balanced improvements in dietary quality, water use, and affordability. In contrast, the HUS and MED diets, with more meat and seafood consumption, showed weaker performance across all three indicators. The results highlight a balanced diet or vegetarian diet appears to be the key to achieving sustainable agricultural systems and healthy diets. By setting different transition parameters, we found consistent results across different transition time frames (Figure S9-S11) and speeds (Figure S12-17).

It is also worth noting that although we consider national dietary differences in the scenario design, there may still be many complex challenges in implementing dietary transitions. Cultural and social factors may hinder the process of promoting healthier foods in certain countries. For instance, in 2015 the Chinese government implemented a policy to promote potatoes as a staple food in order to improve food security and reduce environmental impacts. However, the implementation of this policy has been slow due to the strong influence of the traditional rice and wheat culture in China. Furthermore, countries have diverse perspectives on what constitutes a healthy and sustainable diet. In poor or developing regions, people generally believe consuming more meat is better, while downplaying the health effect of seafood, vegetables, and fruits. This may lead to discrepancies between the actual eating behaviour and their desire for healthy and sustainable diets. Addressing these challenges will necessitate guidance and protection from institutions, laws, and policies, and may require a long transition period, which means that it is very important to examine and respond to potential challenges in the process of the dietary transitions.

Compared with the research results of those single regions or highly aggregated regions, our study provides more spatial detail and demonstrates the differential impacts of dietary transitions across countries to reveal the challenges that different countries may face in the dietary transition over time. It is worth noting that a recent study utilizing an economy-wide general equilibrium model has provided insights into the effects of adopting an EAT-Lancet diet primarily focusing on the economic, social, and environmental spillovers arising from dietary transitions specifically by 2030. While our affordability results are consistent with these findings, the study only focused on comparing the impact of the dietary transition in the endpoint state, missing the impact and potential benefits during and after the transition. According to our results and prior research, it is evident that in the absence of dietary interventions or explicit incentives for dietary transitions, food consumption and dietary patterns in countries do not inherently evolve towards healthier, sustainable, or equitable as income and population continue to rise. Therefore, it is necessary to further explore the long-term impacts before and after the completion of...
dietary transitions to avoid the environmental and economic challenges encountered prior to their completion. A more general of the research lies in its country-level insights into the trade-offs and synergies between health, affordability, and environmental sustainability during and after the dietary transitions. The findings emphasize the need for country-specific approaches to promote healthy and sustainable diets and maintain the safe planetary boundaries. We demonstrate the dynamic nature of the food system and reveal potential challenges and the long-term benefits of supporting healthy and sustainable diets.

**Limitations**

Our study has some caveats and limitations. While we assessed the change in dietary quality resulting from the dietary transition based on the Alternative Healthy Eating Index (AHEI), this approach does not fully capture the effect of dietary transitions on dietary-related premature death. Therefore, our results may underestimate the health effects associated with the dietary transition. In addition, our study mainly focused on the impact of dietary transitions on water use, dietary quality, and affordability. However, we recognize that there are other significant impacts that were not quantified in this paper, such as GHG emissions, health problems related to agricultural pollution, and biodiversity loss. Furthermore, our study is subject to uncertainties surrounding the representation of consumer behaviour in global dynamic agro-economic models. Although we did sensitivity analysis on timeframe and transitioning patterns multi-model intercomparison is necessary to verify the robustness.

**Method**

**Land-use modelling with MAgPIE**

The MAgPIE model is a computational tool designed to simulate the global environmental impacts of agricultural land use and management. MAgPIE employs a global economic model to estimate the impact of different agricultural policies and technologies on a range of environmental indicators, including water use (Figure S1). A key strength of MAgPIE is its ability to perform a detailed analysis of the trade-offs between multiple environmental indicators. For example, the model can assess the impact of transitions in dietary patterns on water use, food prices, and land use. In this way, MAgPIE can offer insights into the complex interplay between various factors and facilitate evidence-based policymaking that balances the benefits of agricultural production with its environmental impacts. This study uses the latest version of MAgPIE (4.6.3) to identify the impact of dietary transitions on the environment, health, and affordability at the country level. We set up two-time frames, assuming that the dietary transitions are completed in 2030 or 2050, to examine changes in food prices and total water use (Figure S2). Due to space constraints, we primarily present the results for the 2050 dietary transition, with other results presented in the Supporting Material (Figure S9-S11).

**Food consumption under different dietary scenarios**
In the MAgPIE model, the regional food energy demand is defined according to the regional diet for a given population from exogenous sources in 10 food energy categories. In our study, the regional food energy demand in the BaU scenario is derived from a cross-country regression analysis combined with GDP and population growth under the SSP2 development scenario\(^3^4\). As the MAgPIE model aggregates certain food components (e.g., fruits, vegetables, and nuts are lumped together as “others”) which are too coarse for assessing nutritional quality (Table S1), we disaggregated the MAgPIE food consumption data according to the average proportions of different foods in the FAO Food Balance Sheets\(^2^4\) from 1995 to 2020.

We selected four common healthy diets\(^3^5\): the Mediterranean dietary (MED) as defined by Bach-Faig et al (2011)\(^3^6\), the EAT-Lancet reference diet (EAT)\(^9\), dietary patterns from the 2015–2020 Dietary Guidelines for Americans (HUS)\(^3^7\), and a vegetarian scenario (VEG), assuming complete dietary transitions in 2050. To better analyze the impact of different diets on the environment, health, and affordability, the four dietary patterns were assessed at the 2500 kcal per day level. For detailed settings. We assumed that the dietary transitions are linear in the main text. Meanwhile, we also follow two type curves, starting in 2020 to gradually replace the dietary structure (See Figure S12-S17), so as to perform a sensitivity analysis of the results.

**Impact of water use**

The escalating impact of global agricultural production on water resources, coupled with the surging global population and transitioning dietary patterns, underscores the urgent need to capture water use patterns across different food categories. In the MAgPIE model, water use data are obtained from multiple sources, such as national statistics, model parameters, remote sensing, and agricultural policy and market data. By integrating these data, the MAgPIE model can estimate water use for different regions, crops, and irrigation methods at the 0.5-degree grid cell level under different dietary patterns\(^3^8\).

**Impact on dietary quality**

We chose the Alternate Healthy Eating Index (AHEI)\(^3^9\) to evaluate the relationship between diet and health. We scored nine components of the AHEI for each stratum. These components include fruit, non-starchy vegetables, grains, sugars, legumes/nuts, red meat, omega-3 fats, polyunsaturated fatty acids (PUFAs), and \textit{trans} fats (sodium is not estimated in the MAgPIE model). Each component was scored from 0 to 10, and the final score ranged from 0 to 90 (Table S2).

**Impact on food affordability**

As MAgPIE is an economic optimization model that operates under constrained conditions, it can derive a food shadow price for each country’s food demand constraint. In this study, we calculated food expenditures in different countries based on food prices and consumption. Food affordability was defined as the share of total food expenditure in total personal consumption expenditure, which was obtained from the model output.
Synergies and trade-offs

Finally, we analyzed the synergies and trade-offs of different dietary transitions by calculating the relative change of three indicators relative to the BaU scenario in the other four dietary scenarios of all countries from 2020–2100.

\[ S_{i^+} = \frac{(x' - x_{BaU})}{x_{BaU}} \]

1

\[ S_{i^-} = \frac{(x_{BaU} - x')}{x_{BaU}} \]

2

where \( S_{i^+} \) and \( S_{i^-} \) respectively indicates the relative change of positive (dietary quality) indicator \( i^+ \) and negative (water use and food affordability) indicator \( i^- \). \( x' \) represents the value of each indicator for different scenarios, and \( x_{BaU} \) represents the value of each indicator for the BaU scenario. If \( S > 0 \), it means that dietary transition can have a positive impact on indicators (synergies), and if \( S < 0 \) means that there is a negative impact (trade-offs).

Declarations

Data availability

Data supporting the findings of this study are available within the article and its Supplementary Information files or are available on figshare (https://doi.org/10.6084/m9.figshare.23905866).40

Code availability

The model code of the MAgPIE model is openly available under the GNU Affero General Public License, version 3 (AGPLv3) and accessible via GitHub (https://github.com/magpiemodel/magpie). The release version (MAgPIE 4.6.5.), on which this study is based, has been archived via Zenodo (https://doi.org/10.5281/zenodo.7782037).

Acknowledgement

This study is financially supported by the National Natural Science Foundation of China (42077060) and the Start-up Fund of Huazhong Agricultural University to Zhen Wang.

Author contributions

ZW and YH conceived the study. ZW designed the study methodology. ZD, JW, and CL collected the data, did the data analysis and visualization. ZD drafted the manuscript. BB, ZW, YH, and PH reviewed and edited the manuscript. BB and ZW supervised all the work.
Competing interests

All other authors declare they have no competing interests.

References


24. FAOSTAT. (Food and Agriculture Organization); http://faostat.fao.org.


40. Deng, Z. C. et al. Supplementary data and source data for "Transitioning to healthy and sustainable diets has high environmental and affordability trade-offs for developing countries". figshare; 2023. https://doi.org/10.6084/m9.figshare.23905866

Figures
Figure 1

Changes in water use due to dietary transitions. A) shows the water use at global scale over time; b) shows water use at the country level in 2020; c-n) show the spatial distribution of changes relative to BaU for different diets in 2030, 2050 and 2100.
Figure 2

Average AHEI component scores; a) Average AHEI component scores by food items in 2020 and 2100; b) AHEI score for 2020 in different countries; c) Change in 2100 under BaU scenarios of each country; d) AHEI score and difference with BaU in 2100 under four diets across countries
Figure 3

Share of food expenditure in different dietary scenarios from 2020-2100. A) share of food expenditure in different dietary scenarios at the global level over time; b) expenditures by food category in different diets (Unit: USD per capita); c-d) share of food expenditure in different countries in 2020 and 2100 under the BaU scenario; e) percent change relative to BaU; red number indicate the amount by which the country’s burden increased; blue number indicates the opposite
Figure 4

Synergies and trade-offs associated with different dietary transitions at global level over time; If the point is in the first quadrant, it means that dietary transitions can provide a triple win for dietary quality, water use and food affordability; If in quadrant II, it means dietary transitions can have benefits for dietary quality and water use, but at the expense of food affordability trade-offs; If in quadrant III, it means dietary transitions can only have benefits for dietary quality, but at the expense of food affordability and water use trade-offs; If in quadrant IV, it means dietary transitions can have benefits for dietary quality and food affordability, but at the expense of water use trade-offs
Figure 5

Changes in country quadrants over time associated with the EAT diet; a) number of countries in different quadrants over time; b) synergies and trade-offs; c-e) Distribution in different country quadrants and changes in 2030, 2050, and 2100

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarydata1.xlsx
- Supplementarydata2.xlsx
- Supplementarydata3.xlsx
- Supplementarydata4.xlsx
- Supplementarydata5.xlsx
- Supplementarydata6.xlsx
- Supplementarydata7.xlsx
- Supplementarydata8.xlsx
- Supplementaryinformation.docx