Re-Optimization and Evaluation of Global Food Systems: Case Studies from China, USA, and Ethiopia

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***Abstract*—This paper explores the dynamics of global food systems, emphasizing the need for a balanced approach between efficiency, profitability, equity, and sustainability. Using case studies from China, the USA, and Ethiopia, the study develops a re-optimization model to reorder the significance of these indicators. By collecting data on 18 indices from 2000 to 2020, models for efficiency, profitability, equity, and sustainability are built using methods like the logistic model, Runge-Kutta method, and linear programming. The results are synthesized into a Prioritized Food System Index (PFSI), which provides insights into how shifting priorities impact the food system's stability. The analysis highlights the trade-offs between economic goals and social-environmental outcomes, discussing benefits and costs for both developing and developed countries. Ultimately, the study offers a roadmap for improving food systems while ensuring sustainability and equity, fostering adaptability to various national contexts.**

I. Introduction

A. Background

The food framework envelops all human exercises connected with food creation, handling, circulation, and utilization [1]. Its intricacy lies in the transaction of different drivers, criticism components, and results, alongside its interconnectedness with other human frameworks. A huge part of food frameworks is their job in addressing **food security** — guaranteeing widespread admittance to adequate and nutritious food to address dietary issues [2]. For example, the 2021 UN Food Frameworks Highest point stressed focusing on worldwide sustenance as a pathway to supportability and value [3].

Regardless of these desires, current worldwide food frameworks focus on market proficiency and benefit expansion, frequently fueling disparities [4]. Weak gatherings face difficulties in gathering fundamental food needs because of cost control, exchange elements, and territorial abberations. Subsequently, issues like food waste and deficiencies endure — delineated by the concurrence of worldwide ailing health (10.7% in 2016) and wastage of almost 33

B. Restatement of the Problem

To make a stable and enhanced food framework, a model tending to various targets is significant. As a feature of our consultancy for the Global Foods The board (ICM) Council, we propose the accompanying undertakings:

- Distinguish basic elements and goals of the food framework, choosing agent markers.
- Foster a far reaching assessment model for current food frameworks.
- Enhance the food framework for further developed targets and contrast and current circumstances, examining attainability.
- Inspect compromises, including benefits and related costs.
- Apply the model across nations at various improvement levels and investigate results.
- Survey the model's flexibility and adaptability for different applications.

Fig. 1. Sustainable food systems [5]

C. Our Work

Our work process is outlined in the accompanying diagram:

II. Assumptions and Justifications

We make the accompanying presumptions in the demonstrating system:

Assumption 1. *Country as the unit of analysis.* Assessments are directed at the nation level, taking into account food framework goals like productivity, proficiency, value, and maintainability.

Assumption 2. *Neglecting imports and exports.* Every nation is treated as independent, with equivalent food conveyance inside. This is legitimate as most significant nations have a food independence rate above 0.8 [6].

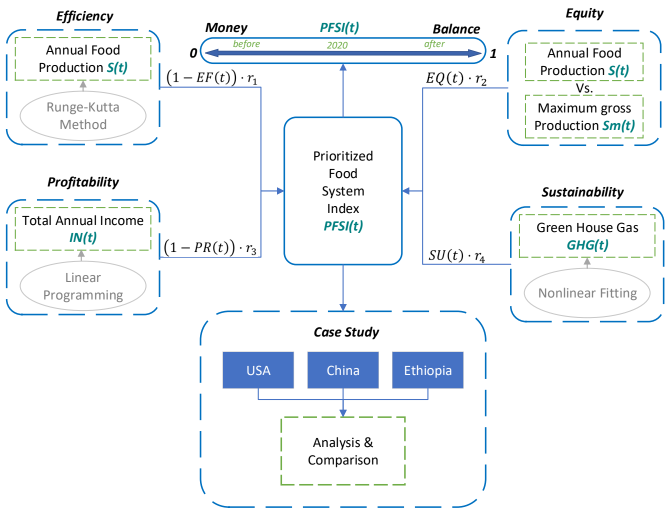

Fig. 2. Structure of the model and paper

Assumption 3. *Data reliability.* All gathered information from solid sources (e.g., FAO, World Bank, Statista, Worldometers) is expected exact [7]–[10].

Assumption 4. *No unanticipated regular disasters.* The model accepts no unexpected occasions (e.g., dry seasons, floods) that could disturb the food framework.

Assumption 5. *Continuous populace changes.* Populace changes are thought to be steady, with no huge interruptions like mass relocations or wars.

III. Model Preparation

A. Notation

In this paper, we characterize a few images and boundaries, and their documentations are displayed in Table I.

IV. Model Design

To finish our model for the food framework, we use EF, EQ, PR, and SU to indicate the effectiveness, value, productivity, and supportability scores, individually. The last food framework file $PFSI$ is determined by means of a weighted typical cycle.

A. Preparation: Calculated Populace Forecast Model

We utilize a calculated model for populace guaging [11], as it represents limitations like regular assets, natural limit, and strategies. The calculated model is given by

$$\frac{\mathrm{d}P}{\mathrm{d}t} = r_0 \left(1 - \frac{P(t)}{P_{\max}}\right) P(t),$$

where r_0 is the development rate, and $P_{\max}$ is the most extreme populace. The retrogressive distinction condition for populace is

$$\frac{P(k) - P(k-1)}{P(k)} = r_0 - s \cdot P(k), \quad k = 2, 3, \ldots, 21.$$

We fit the boundaries r_0 and $P_{\max}$ utilizing the straight least squares technique, as displayed in Table II. The insightful arrangement is

$$P(t) = \frac{P_{\max}}{1 + \left(\frac{P_{\max}}{P_{2020}} - 1\right) e^{r_0(t-2020)}}.$$

B. Model for Assessing EF

Effectiveness in the food framework is the proportion of results to inputs [12]. We characterize effectiveness as the complete yield of various food sources, following [13]. The all out yield is given by

$$S = \sum_{i=1}^{6} s_i,$$

where s_i is the yield of the i-th food. The objective yield in year t is

$$S_m(t) = \frac{S_{2020}}{(1 + OR_{2020} - UR_{2020})} \cdot p(t),$$

where OR and UR are corpulence and undernutrition rates, individually. The yield $S(t)$ advances as per the strategic condition

$$\frac{\mathrm{d}S}{\mathrm{d}t} = PM \cdot \left(1 - \frac{S(t)}{S_m(t)}\right) S(t),$$

with starting condition $S_{\text{initial}} = S_{2020}$. The mathematical arrangement is gotten utilizing the Runge-Kutta strategy. The outcome is standardized utilizing min-max standardization:

$$EF(t) = \frac{S(t) - S_{\min}}{S_{\max} - S_{\min}}.$$

C. Model for Assessing EQ

Value issues in the food framework incorporate prejudice, destitution, and orientation imbalance [14], [15]. We characterize value as the proportion of supply to request, $S(t)/S_m(t)$, mirroring the accessibility of food comparative with need. The outcome is standardized in basically the same manner to EF.

D. Model for Assessing PF

Benefit is characterized as the complete pay from food deals, taking into account food costs. We utilize direct programming to expand benefit, dependent upon the limitations on food yields:

$$\max \quad \sum_{i=1}^{6} \left(s_i \frac{PR_i}{IF}\right),$$

dependent upon

$$\sum_{i=1}^{6} s_i = S(t),$$

furthermore, yield imperatives throughout the course of recent years:

$$\min\left(\frac{s_k(t-j)}{S(t-j)}\right) \le \frac{s_k(t)}{S(t)} \le \max\left(\frac{s_k(t-j)}{S(t-j)}\right), \quad j = 1, 2, 3, \ldots, 5.$$

The outcome is standardized in basically the same manner to EF.

TABLE I
NOTATIONS

Symbols	Description	Units
t	time	year
PM	Policy motivation, an adjustable constant	1
UR_{2020}	Undernourishment rate in 2020	%
OR_{2020}	Obesity rate in 2020	%
$p(t)$	Population	person
p_{2020}	Population in 2020	person
$S_m(t)$	Target total yield in year t	ton
$S(t)$	Total yield	ton
S_{2020}	Total yield in 2020	ton
$s_1(t)$	Target total yield of cereal in year t	ton
$s_2(t)$	Target total yield of fruit in year t	ton
$s_3(t)$	Target total yield of oil crops in year t	ton
$s_4(t)$	Target total yield of vegetables in year t	ton
$s_5(t)$	Target total yield of dairy in year t	ton
$s_6(t)$	Target total yield of meat in year t	ton
$PR_i(t)$	The corresponding average prices for six different foods in year t	$/ton
IF	Average inflation rate of the studied country from 2000 to 2020	%
$IN(t)$	The annual income of the Food sales in year t	100000 $
$GHG(t)$	Total greenhouse gas emissions from agriculture in year t	CO_2 equivalent
r_1	Weight of efficiency	1
r_2	Weight of equity	1
r_3	Weight of profitability	1
r_4	Weight of sustainability	1
rs	Relative significance of EQ (or SU) with respect to EF (or PF)	1
$EF(t)$	Score of efficiency in the food system	1
$EQ(t)$	Score of equity in the food system	1
$PF(t)$	Score of profitability in the food system	1
$SU(t)$	Score of sustainability in the food system	1
$PFSI(t)$	Prioritized food system index	1

E. Model for Assessing SU

Manageability is characterized by the discharges from horticulture per unit of food yield. We fit the information for ozone depleting substance discharges and yield utilizing direct relapse:

$$GHG(t) = at - b, \quad S(t) = ct - d.$$

The proportion of emanations to yield is then

$$\frac{GHG(t)}{S(t)} = \frac{at-b}{ct-d}.$$

After a strategy change in 2020, we update this proportion with strategy inspiration PM:

$$\frac{GHG(t)}{S(t)} = \frac{a(t-2020)+(2020a-b)(1-PM)}{c(t-2020)+(2020c-b)(1-PM)}.$$

The outcome is standardized like EF.

F. Model for Assessing PFSI

The focused on food framework file $PFSI$ is determined by weighted summation of EF, EQ, PR, and SU:

$$PFSI(t) = (1-EF(t))r_1 + (1-PR(t))r_3 + EQ(t)r_2 + SU(t)r_4.$$

Loads are acquired by means of the Insightful Order Cycle (AHP). The correlation network A is

$$A = \begin{bmatrix} 1 and 1 and 1/rs and 1/rs \\ 1 and 1 and 1/rs and 1/rs \\ rs and rs and 1 and 1 \\ rs and rs and 1 and 1 \end{bmatrix}.$$

In the wake of tackling for the eigenvector and normalizing, the loads are approved utilizing the consistency file CI and consistency proportion CR.

TABLE II
VALUES OF r_0 AND P_{max}

	r_0	P_{max}
China	-0.0219	1.83×10^9
USA	-0.0332	0.408×10^9
Ethiopia	-0.0381	0.328×10^9

V. DISCUSSION

A. Re-Improvement for the Food System

- **For nations with undernourishment rates lower than corpulence rates:** Food creation will at first decline, bringing down effectiveness (EF). When populace development balances out, food yield and value will move along. Manageability stays consistent, with GHG emanations diminishing quicker after re-advancement.
- **For nations with higher undernourishment rates than stoutness rates:** Food creation will increment to address populace issues. Assuming populace development is higher than food creation, value will at first reduction yet ultimately balance out. Manageability and productivity pursue comparable directions.

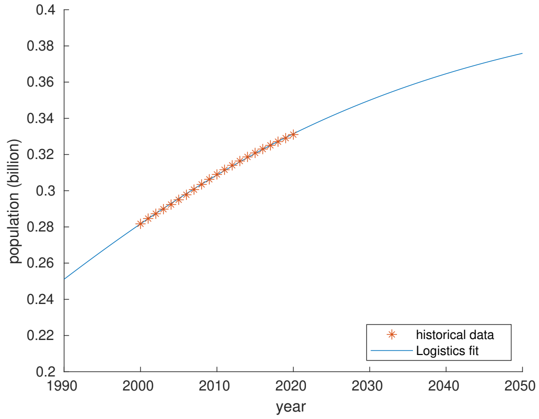

Fig. 3. Logistic Fit of Population of USA.

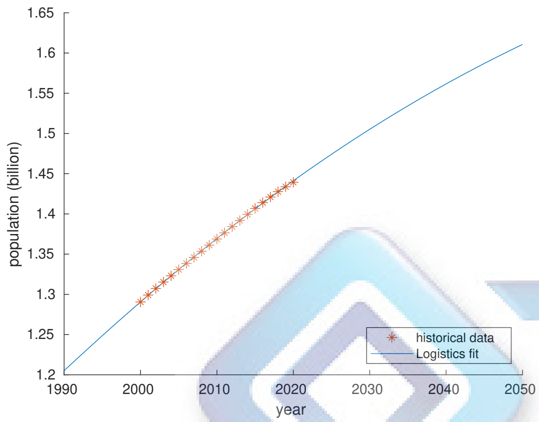

Fig. 4. Logistic Fit of Population of USA.

Balance Value: When $PFSI > 0.5$, maintainability and value are focused on over effectiveness and benefit. The's framework will likely boost benefits while keeping up with reasonableness and maintainability.

B. Benefits and Costs

1) Potential Benefits:

- **Equity improvement** in created nations, with a slight downfall followed by recuperation in emerging nations.
- **Sustainability improves** in both created and agricultural nations, with GHG discharges diminishing all the more discernibly in created nations.

2) Potential Costs:

- **Developing countries** may battle to at first stay aware of populace development.
- **Profitability** diminishes for both created and emerging nations because of yield impediments and expansion.

3) Occurrence of Advantages and Costs:

- **Benefits happen prior in agricultural nations (e.g., Ethiopia in 2025)** contrasted with created nations (e.g., China in 2045, USA in 2051).

C. Case Studies

1) China:: China's food framework will at first decrease creation until 2035, trailed by a consistent increment to fulfill rising populace needs. Value improves with better food appropriation. The re-streamlined framework arrives at balance after roughly 25 years of strategy inspiration.

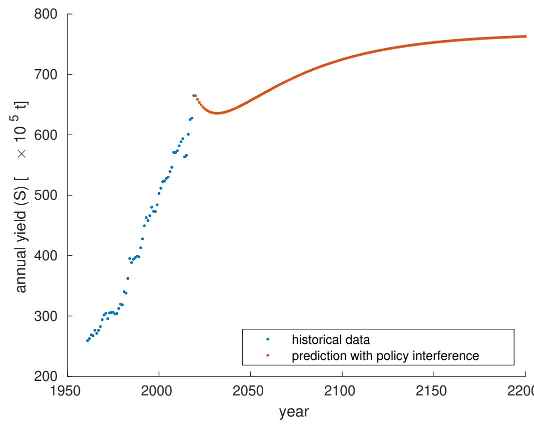

Fig. 5. Annual Yield of China with Policy Interference.

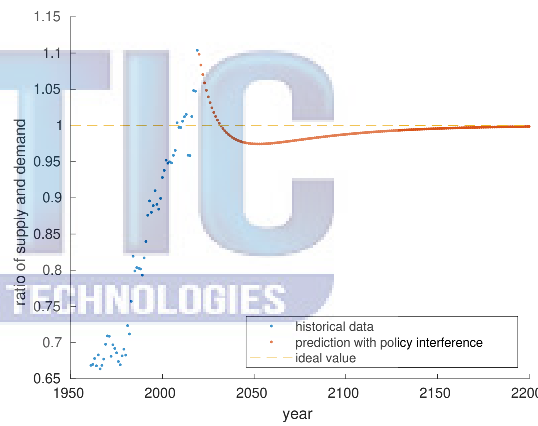

Fig. 6. Ratio of Supply and Demand of Food of China with Policy Interference.

VI. Sensitivity Analysis

In our model, the approach inspiration (*PM*) and relative importance (*rs*) are set for arbitrary reasons: *PM* impacts strategy strength, set to 0.1 for China and the USA, and 0.5 for Ethiopia; *rs* characterizes the heaviness of value and supportability in the food framework, set to 7. This part tests whether the model outcomes are delicate to varieties in these boundaries.

A. PM Variance Test.

We test *PM* values somewhere in the range of 0.04 and 0.4 to survey its effect on the yearly yield and value record. In spite of critical varieties in *PM*, the patterns of both the yield and value record stay unaltered: the yield diminishes to a base and increments towards a proper asymptote, while the value

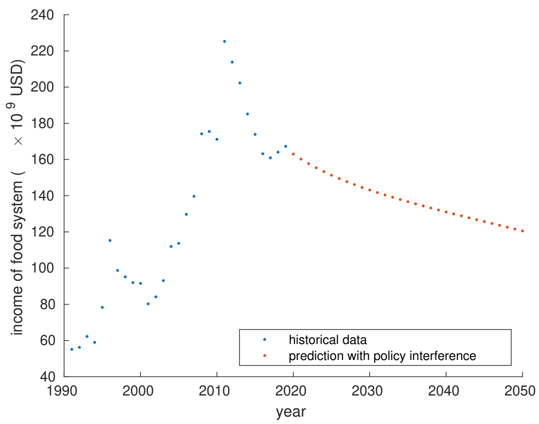

Fig. 7. Income of Food System of China with Policy Interference.

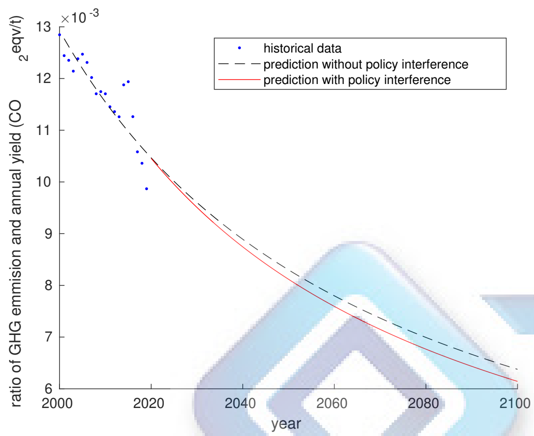

Fig. 8. Greenhouse Gas Emission per yield of the Food System of China with Policy Interference.

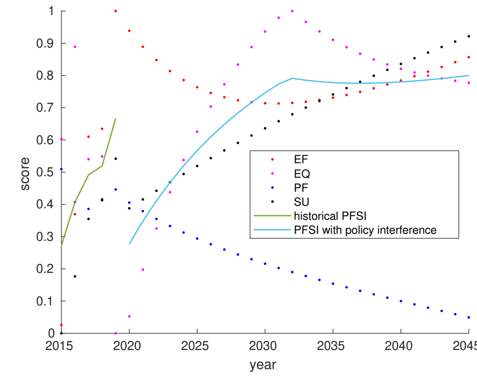

Fig. 9. *PFSI* of China with All Four Factors Specified from 2015 to 2045.

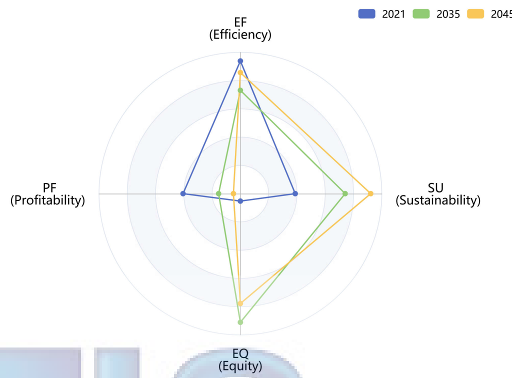

Fig. 10. The Change of Four Factors of China's Food System.

file meets to 1 over the natural course of time. These outcomes show that the model's results are strong to *PM* vacillations.

B. *rs* Change Test.

We additionally test *rs* values somewhere in the range of 1 and 8. The recalculated Focused on Food Framework List (*PFSI*) shows negligible variety notwithstanding changes in *rs*. The pattern of *PFSI* stays reliable, expanding quicker at first and afterward easing back around 2040. This affirms that the model isn't profoundly delicate to *rs* changes.

VII. Strengths and Conceivable Improvements

A. Strengths

- **Practicality:** Our model records for six nutritional categories, lined up with the dietary pyramid, guaranteeing true significance.
- **Global Perspective:** The model offers a worldwide view, reasonable for crosscountry correlations without zeroing in on inner elements.
- **Flexibility:** By changing *PM*, we can shift the model's prioritization of effectiveness, manageability, and value, making it versatile to various strategy situations.

B. Improvements

- **Imports and Exports:** The model doesn't represent food exchange, which might decrease its precision in exchange subordinate nations.
- **Expanded Indicators:** Including more factors, for example, the match among dietary and creation designs or expenses of creation, would work on the model's fulfillment, particularly with respect to maintainability.

VIII. Conclusions

In this review, we proposed an exhaustive structure for dissecting and enhancing food frameworks in light of changing populace elements, financial tensions, and natural difficulties. Our methodology starts with the reception of a strategic model to gauge populace development from 2020 to 2050. This step is basic for understanding the potential food interest in various districts and considers more exact expectations on the stock requirements of worldwide food frameworks. By utilizing populace projections, we guarantee that our food framework models are receptive to the patterns in segment changes, which are a vital driver of food security and maintainability.

We then, at that point, created four unmistakable models to survey key execution marks of the food framework: effectiveness, benefit, value, and supportability. These measurements are imperative for assessing the adequacy of food framework re-streamlining, as every district might focus on various results

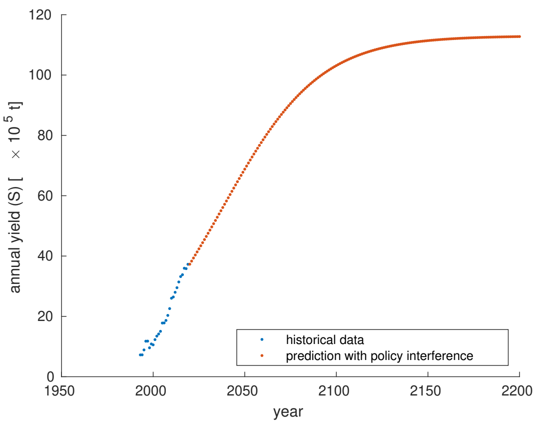

Fig. 11. Annual Yield of Ethiopia with Policy Interference.

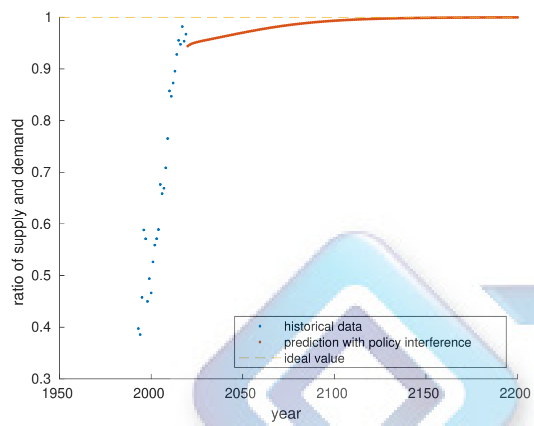

Fig. 12. Ratio of Supply and Demand of Food of Ethiopia with Policy Interference.

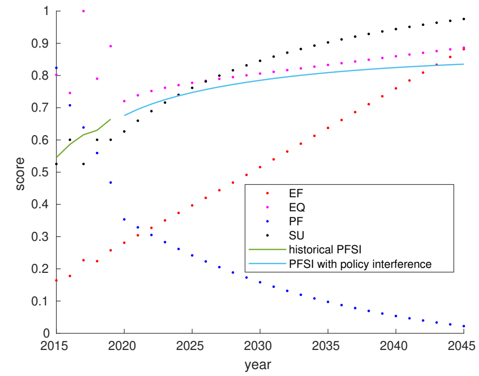

Fig. 13. *PFSI* of Ethiopia with All Four Factors Specified from 2015 to 2045.

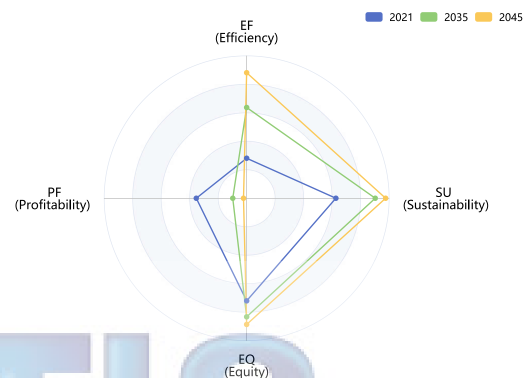

Fig. 14. The Change of Four Factors of Ethiopia's Food System.

relying upon its advancement status and objectives. Proficiency estimates how well the food framework uses accessible assets, benefit surveys the monetary feasibility of food creation, value sees how well food assets are disseminated across populaces, and supportability assesses the drawn out natural and biological strength of the food framework.

To tackle the models, we utilized a blend of differential conditions, straight programming, and direct fitting methods. These techniques gave a thorough way to deal with model the perplexing cooperations inside food frameworks, permitting us to decide the ideal designation of assets across various districts and areas. The utilization of differential conditions helps catch the dynamic and associated connections between populace, food creation, and ecological elements. Straight programming works with the recognizable proof of the best arrangements under asset imperatives, while direct fitting strategies permit us to display drifts and anticipate results over the long run with sensible precision.

A critical commitment of this paper is the presentation of the Focused on Food Framework Record (PFSI), a list intended to evaluate and focus on the goals of a food framework. The PFSI is expected to direct policymakers in pursuing informed choices by unequivocally gauging the significance of different factors like productivity, value, and maintainability. By changing the weightings in the PFSI, the food framework can be re-advanced to zero in on the most basic areas of concern, whether it decrease food uncertainty, upgrading natural supportability, or further developing productivity.

In the conversation segment, we examined the likely advantages and expenses related with re-streamlining the food framework. We investigated the results for both created and emerging nations, perceiving that the difficulties and amazing open doors for food framework re-advancement vary altogether across locales. Specifically, created nations might encounter transient decreases in food creation as they progress toward a more manageable framework, yet after some time, manageability improves with a decrease in ozone harming substance outflows. Then again, agricultural nations might confront starting battles to satisfy the increasing need because of higher populace development rates, however long haul value and supportability upgrades are normal as these nations adjust.

We likewise directed contextual analyses on China, the USA, and Ethiopia to investigate how the proposed models can be applied in unambiguous public settings. In China, we found that food creation would at first decay prior to bouncing back to address the issues of a developing populace. The re-enhancement process further develops food value, yet

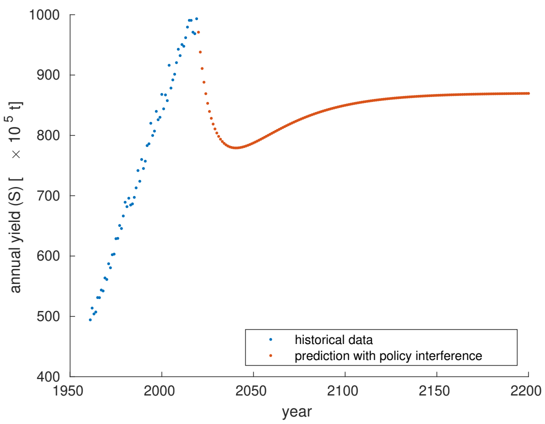

Fig. 15. Annual Yield of USA with Policy Interference.

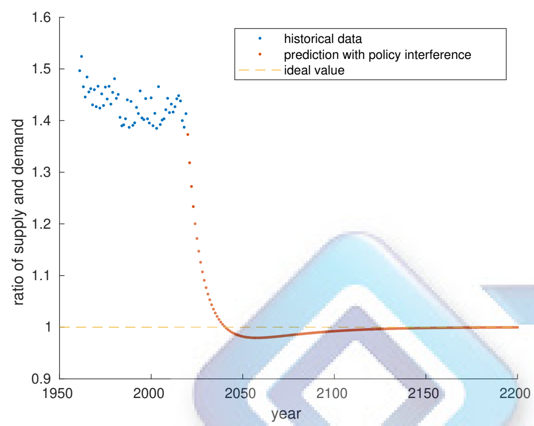

Fig. 16. Ratio of Supply and Demand of Food of USA with Policy Interference.

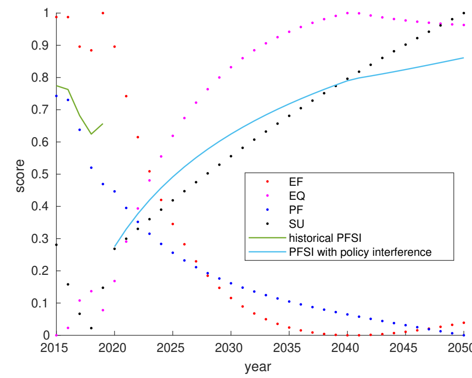

Fig. 17. *PFSI* of USA with All Four Factors Specified from 2015 to 2045.

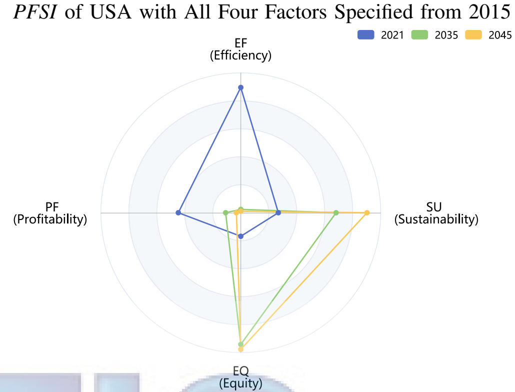

Fig. 18. The Change of Four Factors of USA's Food System.

it requires a drawn out obligation to strategy changes and development. In Ethiopia, the advantages of re-enhancement manifest a whole lot earlier, with upgrades in manageability and value being acknowledged in the early long periods of execution. Conversely, the USA's framework demands greater investment to change, with a harmony among productivity and maintainability being accomplished toward the middle of the century. These contextual investigations give important bits of knowledge into the versatility and flexibility of our model across assorted public settings.

Furthermore, we examined the adaptability of our methodology and its true capacity for transformation to various food frameworks around the world. While our model was created in view of explicit nations, its fundamental standards can be applied to different areas with changing degrees of advancement, horticultural practices, and strategy conditions. The adaptability of the model lies in its capacity to conform to the neighborhood setting, whether with regards to food creation limit, financial circumstances, or ecological supportability objectives. This makes the model a helpful instrument for worldwide food framework arranging and strategy improvement.

At last, we directed a responsiveness examination to investigate the impact of strategy inspiration on the food framework record. This examination featured the significance of proactive approach choices in forming the future direction of food frameworks. By reproducing different strategy situations, we saw how changes in legislative spotlight — whether on further developing maintainability, value, or productivity — can essentially impact the results of food framework improvement. The outcomes highlight the significance of strategy arrangement with long haul manageability objectives and the requirement for versatile administration structures that can answer evolving conditions.

All in all, this work gives a strong groundwork to additional innovative work in food framework streamlining. While the models introduced here are extensive, there is generally opportunity to get better. Future work could incorporate more granular information, consolidating ongoing observing of food framework execution, and extending the model to represent extra factors, for example, environmental change influences, mechanical headways, and changes in worldwide exchange designs. By expanding on this work, we can assist with making a stronger, productive, and evenhanded worldwide food framework for people in the future.

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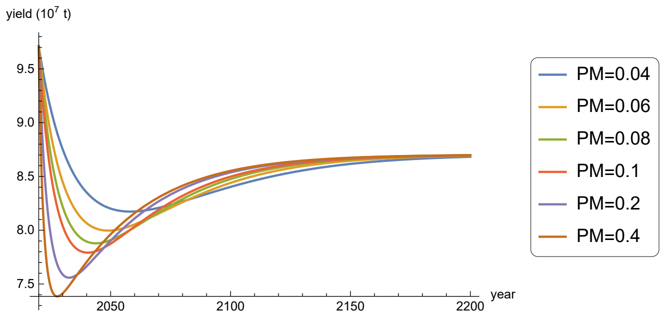
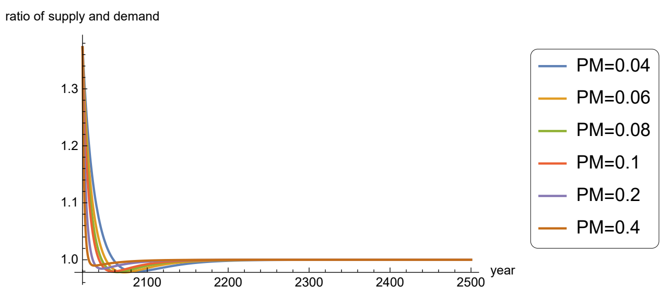


(a) Re-calculating of Annual Yield of USA with Different Values of *PM*.



(b) Re-calculating of Equity Index of USA with Different Values of *PM*.

Fig. 19. Sensitivity Test for Policy Motivation *PM*.

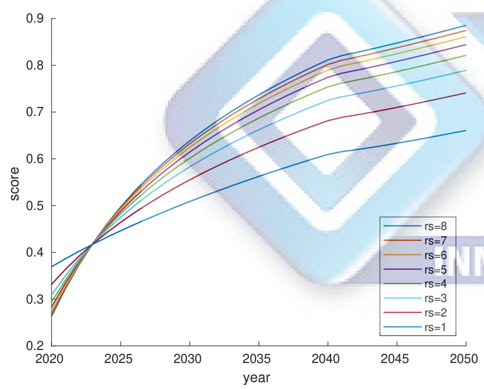


Fig. 20. Sensitivity Test for rs by Re-calculating the Corresponding *PFSI*.

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Appendix A
Supporting Figures

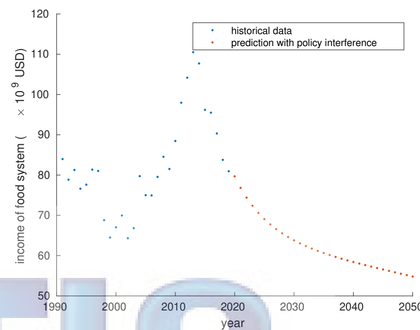

Fig. 21. Income of Food System of USA with Policy Interference.

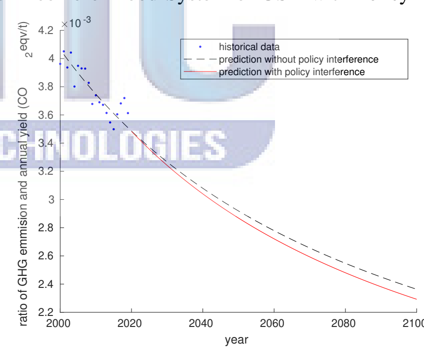

Fig. 22. Greenhouse Gas Emission per yield of the Food System of USA with Policy Interference.

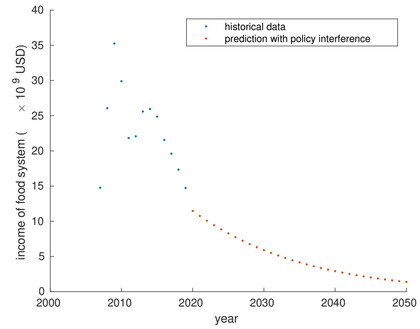

Fig. 23. Income of Food System of Ethiopia with Policy Interference.

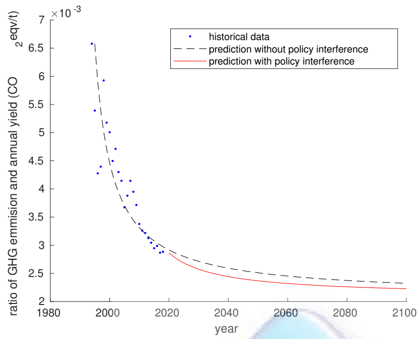

Fig. 24. Greenhouse Gas Emission per yield of the Food System of Ethiopia with Policy Interference.

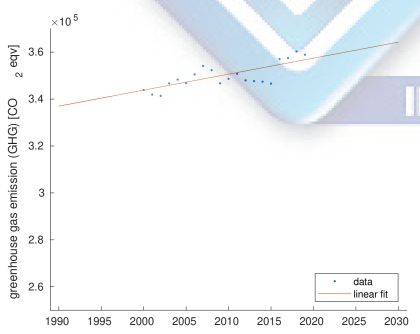

Fig. 25. Linear Fit of the Greenhouse Gas Emission of USA.

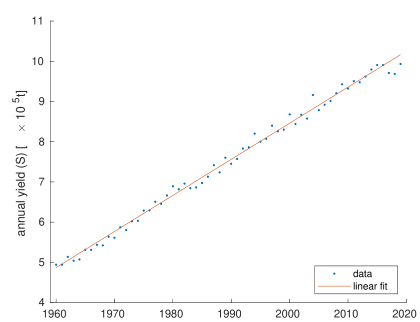

Fig. 26. Linear Fit of the Annual Yield of USA.

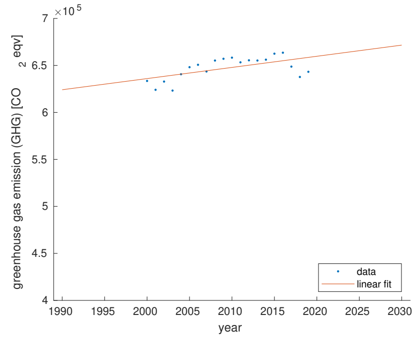

Fig. 27. Linear Fit of the Greenhouse Gas Emission of China.

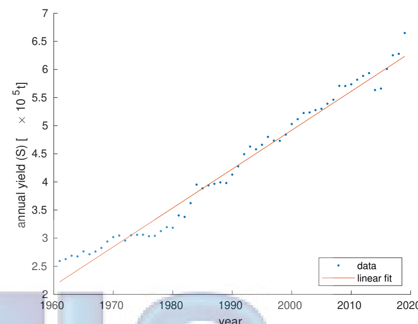

Fig. 28. Linear Fit of the Annual Yield of China.

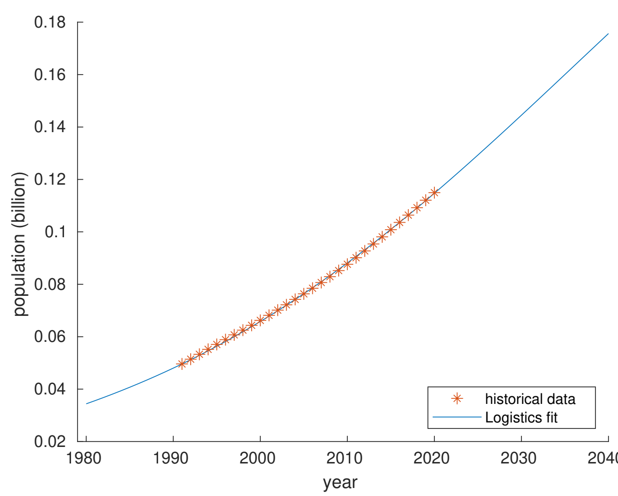

Fig. 29. Logistic Fit of Population of Ethiopia.