UDC 338.439+332.1
JEL Classification: C62, C68, E63
DOI: 10.15587/2706-5448.2025.336241

Zhanar Amangeldiyeva,
Raissa Baizholova,
Danagul Tleuzhanova,
Gulzhan Mukasheva,
Dauren Sarzhanov,
Talgat Zhakupov

DEVELOPMENT OF AN APPROACH TO FORMING A MODEL OF BALANCED DEVELOPMENT OF FOOD SECURITY UNDER CONDITIONS OF TECHNOLOGICAL LOAD

The object of this study is a model of balanced agricultural development to ensure food security in conditions of technogenic stress. This issue is relevant for many countries, which is increasing its food exports to the world market while actively developing industrial production. Technogenic pressure on agricultural land not only negatively affects production volumes, but also product quality, environmental purity and consumer safety.

The proposed approach to forming a model of balanced food security development in conditions of technogenic load allows facilitates the use of strategic components of industrial and agricultural production, thereby enabling the achievement of an optimal balance of development. In this work, the optimal balance is defined as a balance in which the level of influence of new technologies is simultaneously increasing. This approach will also allow for the adjustment of the growth of technological influence on food security. Consequently, the proposed approach will enhance the impact of anthropogenic load on agricultural land and reduce anthropogenic pollution of agricultural land.

As a result of the work, a model of balanced food security development was created for three regions of Kazakhstan – Akmola, Kostanay and North Kazakhstan. To this end, aggregated large-scale coefficients for wheat grain and livestock meat were introduced into the Technological Development model. These products are essential for ensuring food security within the boundaries of the regions under study and for Kazakhstan as a whole. According to the criteria studied, the indicators for the Kostanay and North Kazakhstan regions are approximately the same, at 78.1 and 78.3, respectively. This allows for the large-scale cultivation of agricultural products that are safe for human consumption. For the Akmola region, the indicator is 24.7. This indicator is not critical, but it highlights the need to change production technologies both in agriculture in this region and in industrial production.

The proposed approach can be used to analyse the balanced development of regions with the aim of intensifying food production.

Keywords: *agricultural land, Environmental Technogenic Oppression (ETO) index, TEDR, sustainability level.*

Received: 01.05.2025
Received in revised form: 04.07.2025
Accepted: 24.07.2025
Published: 30.08.2025

How to cite
Amangeldiyeva, Z., Baizholova, R., Tleuzhanova, D., Mukasheva, G., Sarzhanov, D., Zhakupov, T. (2025). Development of an approach to forming a model of balanced development of food security under conditions of technological load. Technology Audit and Production Reserves, 4 (4 (84)), 60–68. https://doi.org/10.15587/2706-5448.2025.336241

1. Introduction

Despite advances in technology, modern society is still concerned about food security issues. Achieving and maintaining food security is an important goal of sustainable development [1]. The development of industrial potential related to food production, including the use of various modern food reproduction technologies, does not solve the problem [2]. It also creates an additional man-made pressure on agricultural land [1]. Global warming and the additional negative trends caused by this phenomenon affect crop yields [3].

Food security is becoming an increasingly serious problem due to man-made conflicts, climate change and economic downturns. Forecasting food security is essential to ensuring sustainable development for individual countries and the global community as a whole. Expert and consensus approaches and surveys are currently used to measure the actual state of food security. Both require significant resources, time and budget [4]. This exacerbates food security issues in various countries around the world.

The Republic of Kazakhstan has significant agricultural resources, which allows it to export food products to other countries around the world [5]. At the same time, the government is concerned about the introduction of "green" economy technologies that would ensure food security with high-quality food products [6]. However, this requires the development of a balanced development model that would allow for the rational development of various areas of agriculture. In addition, the factor of anthropogenic pressure, which has grown stronger due to active industrial development, urbanization and changing climatic factors, creates significant challenges for food security. The impact of anthropogenic factors on agroecosystems, soil degradation, water pollution, and changes in the biological composition of agricultural crops require a comprehensive approach to ensuring sustainable food security [7].

The relevance of making a model for balanced food security development when there's human pressure on farmland comes from the need to bring together different management ideas into the food resource management system.

The study [8] notes that the agro-industrial complex of the Republic of Kazakhstan has all the advantages and opportunities to become a new driver of economic development. The article examines the state of household farms and provides statistical data on the main indicators of the dynamics and structure of livestock production. Also, under consideration, livestock and poultry productivity across all categories of farms in the Republic of Kazakhstan. The role of household production is shown in comparison with other categories of farms. It is noted that even personal household farms play an important role in the country's agriculture and make a significant contribution to ensuring the state's food security. However, this work does not address the issue of creating a model for balanced development even within the borders of the Republic of Kazakhstan.

Returning to the research [4] mentioned above, it is important to note the proposed extreme machine learning model with gradient boosting for predicting monthly transitions in food security status. However, in this study, food security modelling is presented through phases in a 12-month cycle based on key sets of factors. The factors represent changes in climate and land characteristics, the market, conflict, infrastructure, demographics, and life support zones. This model is more suitable for predicting deterioration rather than sustainable development.

A comprehensive study [9] examines smallholder farms and their role in ensuring food security. It notes the impact of technology on the final product and changes in the food security balance. Although the solution to the problem is considered through the factors of balanced development, the main emphasis is on the development of technology without taking into account possible negative impacts.

The study [10] examines the balance of sustainable development in ensuring food security in Kazakhstan and Azerbaijan. However, the study does not take into account man-made factors affecting agribusiness and private farms.

In the study [11] food security is assessed through a sociological survey followed by scenario modelling. However, in this study, the technogenic load was assessed in terms of food safety and the amount of nutrients consumed by humans.

The work [12] presents an analysis of food security in the developed society of the United States. Sustainable development is represented through the provision of quality food to schoolchildren. Accordingly, the models presented cannot be applied to other countries with lower levels of provision for their citizens.

In paper [13] balanced development of food security is considered through climate change. However, only one agricultural sector is analyzed – shrimp farming. Climate change has a major impact on the sustainability of this sector. Therefore, without considering other sectors and influencing factors, it is difficult to talk about an adequate model of sustainable development.

Study [14] analyses the possibility of using additional natural resources from wild crops to ensure food security. However, the study does not take into account the factor of extracting large volumes of plant raw materials from biocenoses and the emergence of strong anthropogenic pressure.

The work [15] allows to draw a parallel between agribusiness and food security. The research highlights the need to study the dynamic and recursive links between access to land, access to food, and the ability to sustain resources to meet long-term needs for sustainable development. This study showed the strong influence of manufacturing enterprises on agriculture and land. However, the statistical model within a single limited society under study is not applicable within the borders of a state or a number of states.

The analysis allows to summarize the main problem: research groups in different countries around the world are addressing the issue of food security within individual societies using a situational approach.

Thus, *the aim of research* is to develop an approach to forming a model of balanced food security development in conditions of technogenic pressure on the agricultural sector. Agriculture is a priority for ensuring food security. At the same time, the development of production and modern technologies is the basis of the country's economic security. Creating a balance for the sustainable development of these areas is a priority task for the study.

To achieve this aim, the following objectives were set:
- to calculate the aggregates and sub-indices necessary for building the model;
- to create a model for balanced food security development in the areas under study;
- to present an example of the practical implementation of the proposed approach.

2. Materials and Methods

The object of this research is a model of balanced development of the agricultural economy to ensure food security in conditions of technogenic stress. Technogenic stress cannot be eliminated in modern industrial society, but it can be balanced according to the criterion of least harm.

The subject of research is the formation of an approach to building a food security model in a society where both industrial production and agriculture are developing intensively. Such an approach allows for the implementation of multifactorial balanced models. Such models are easily adapted to the conditions of a particular society or state as a whole, allow additional factors to be introduced for research, and can be freely implemented in the form of software.

The methods of analysis and synthesis, grouping, comparison, and mathematical modelling were selected to conduct the research. The model is based on the aggregation of "part-whole". This approach is based on the work [16], which allows replacing various influencing factors depending on the analysis situation.

To develop the model, data were collected on the agricultural sector in the Akmola, Kostanay, and North Kazakhstan regions of the Republic of Kazakhstan. A preliminary analysis and synthesis of these indicators was carried out in terms of grain and meat production volumes, domestic consumption and exports. The data was aggregated to form key environmental indicators. The model is based on the Environmental Technogenic Oppression (*ETO*) index.

The input data consists of industry statistics for the Republic of Kazakhstan [17]. The study period is from 2014 to 2024.

The assumptions in this work are limited time intervals associated with the seasonality of agricultural work. Accordingly, depending on the season, the balance of resource use (natural, labor, production, transport) changes.

The research methodology is based on the work [18], taking into account the recommendations of the United Nations Department of Sustainable Development [19]. In particular, the study focuses on examining the costs and benefits of:
- emissions of harmful substances, protection of the atmosphere from pollution;
- consumption of clean water, storage of water resources and protection of coastal areas from pollution;
- preservation of biological diversity;
- rational use of land resources;
- effective combating of desertification and droughts, preservation of forests;
- development of rural areas and sustainability of agriculture;
- environmentally safe use of biotechnology;
- volumes of harmful waste and ensuring the safety of solid waste and wastewater;
- pollution of the environment with toxic, hazardous and radioactive waste.

The *ETO* calculation procedure is based on determining the sub-indices of the level of anthropogenic impact on the environment (*TL*) and the level of anthropogenic pollution of the environment (*TP*). This can be represented by the following diagram (Fig. 1).

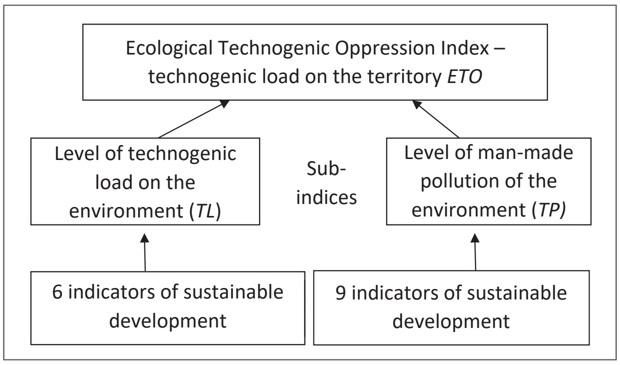

Fig. 1. Structure of the *ETO* index

According to Fig. 1, 15 sustainable development indicators can be used to calculate the *ETO*. These are based on statistical data. Sub-indices are determined with the help of expert assessments in various areas of the economy (Table 1).

To get the *ETO* index from Table 1, let's calculate the aggregates (e):

– degree of industrialization, aggregate E – average of indicators 1–3;

– degree of environmental hazard from businesses, aggregate D – average of indicators 4–6;

– degree of land pollution, aggregate G – indicators 7, 8;

– degree of water source pollution, aggregate V – indicators 9–12;

– degree of atmospheric air pollution, conditional aggregate A, equal to indicator 13;

– degree of biosphere oppression, aggregate B – arithmetic mean of indicators 14, 15.

Based on these aggregates, the *TL* and *TP* sub-indices are formed

$$TL = e^{1+E} e^{1+D};$$
$$TP = e^{G} e^{V} e^{A} e^{B}. \quad (1)$$

An index of technogenic oppression of the territory or ecological technogenic load on the studied territory *ETO* is also formed

$$ETO = TL + TP. \quad (2)$$

In fact, model (2) already allows balancing various indicators to justify the necessary changes in the anthropogenic load on the environment. Based on the *ETO* value, three degrees of anthropogenic oppression of the territory can be identified (Table 2).

To build a model of balanced food security development, it is also necessary to calculate indicators for the economic assessment of the level of technological development of a given territory. This can be achieved by using TEchnological Development of the Region (*TEDR*).

Only then can it be possible to build a model that reflects the balanced development of the territory under study. This index is traditionally formed according to the composite index scheme (Fig. 2).

Table 1

Basic sub-indices for determining the *ETO* index

No.	Indicator name	Sub-indices	
		TL	TP
1	Level of industrialization	+	–
2	Level of concentration of industrial enterprises	+	–
3	Level of solid domestic waste accumulation	+	–
4	Level of control when using natural resources	+	–
5	Level of influence of environmentally hazardous facilities	+	–
6	Degree of technological wear and tear of treatment facilities	+	–
7	Level of land flooding	–	+
8	Degree of land degradation	–	+
9	Water shortage level	–	+
10	Level of drinking water shortage for agricultural needs	–	+
11	Level of contamination of return water	–	+
12	Degree of disruption to the hydrological and hydrochemical condition of rivers	–	+
13	Level of atmospheric air pollution	–	+
14	Prerequisites for the intensification of man-made pollution of agricultural land	–	+
15	Prerequisites for biodiversity decline	–	+

Table 2

Levels of anthropogenic oppression of the territory

ETO	Features
Acceptable value no more than 14 – low	The environment is only slightly degraded and has not yet lost its ability to provide food resources, maintain a good quality of life for the population, and renew itself independently
14–24 – critical value	The environment has changed significantly. There is sufficient resource potential. However, there are signs of a shortage of water, forest and land resources; a decline in the biological diversity of the territory; and atmospheric pollution
More than 25 – threatening	The environment is unable to provide the population with high-quality food and natural resources, including water, land, air, forests and meadows, which have high levels of man-made pollution. A loss of biological diversity in the territory has been recorded

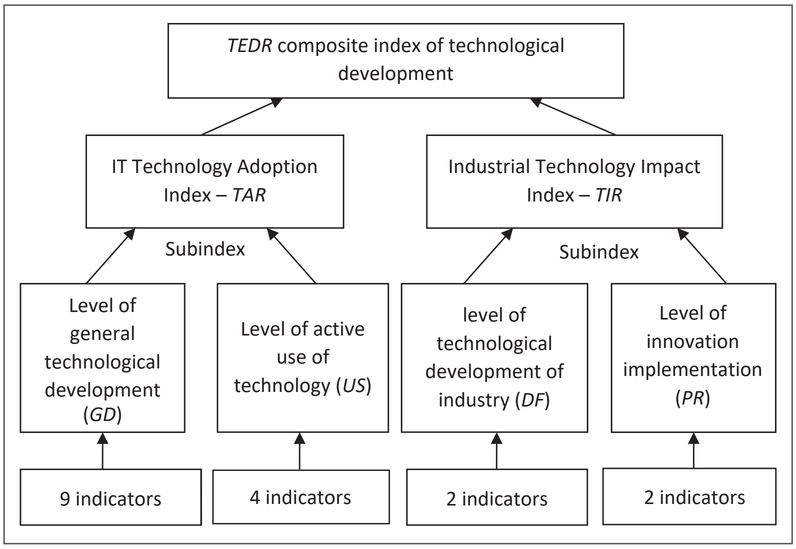

Fig. 2. Structure of the *TEDR* index

According to Fig. 2, when calculating *TEDR*, aggregates are also used, sub-texts are formed, and an index is calculated. Depending on the *TEDR* value, the following levels of technological development of a country can be distinguished: extensive (value up to 19), intensive (20–34), and synergistic (over 35) [18]. The last level is successful for industrial production, but at the same time, the land and natural resources are depleted, and people become dependent on synthetic food sources.

Next, technological development and environmental well-being are evaluated. For this purpose, the *SUTED* (SUstainable TEchnological Development) index is used [19]. A comparison is made between the weighted average values of regional levels of technological development (*TD*) and environmental well-being (*ES*). These are assessed using the $TEDR_k$ and ETO_k indices, calculated for regions k of the country:

$$TD=\frac{w_1TEDR_1+\ldots+w_{25}TEDR_{25}}{w_1+\ldots+w_{25}},$$

$$TD=\frac{w_1TEDR_1+\ldots+w_{25}TEDR_{25}}{w_1+\ldots+w_{25}}, \qquad (3)$$

where *TD* – weighted average value of $TEDR_k$ indices, where k – number of areas, w_k – weight of the k-th area, which is determined by experts and depends on the ratio of the area to the total area of the country. In this case, the area is assessed by the area of agricultural land.

Next, using scale coefficients, it is possible to represent the balance of individual factors affecting food security. The best scenario is when the factor of technological development exceeds the level of technogenic oppression of the territory and is balanced with factors responsible for the preservation of land and other agricultural land. This allows for stable growth in various types of agricultural production. This allows to talk about ensuring food security while actively developing industrial technologies. In this case, sustainable technological development is ensured, the country adapts well to internal and external changes, and technological and environmental processes are in equilibrium, deviation from which is disadvantageous from both points of view.

In other words, any actions aimed at increasing the technological development index (*TD*) cannot be carried out without analyzing their impact on the environmental well-being index (*ES*). Just as opposite actions aimed at reducing the *ES* index cannot be carried out without considering their impact on the *TD* index. Naturally, the balanced situation where *TD* equals *ES* is not constant. Depending on the difference between the values of technological development and environmental well-being (in absolute terms, *SUTED*), various situational zones can be identified (Table 3).

Table 3

Situational zones of balanced development of food security under conditions of technogenic load

Assessment of the situation	The difference between *TD* and *ES* values	*SUTED*
Stable (balanced)	1–22	80 and more
Conditionally balanced	23–34	26–79
Unstable	More than 34	25 and less

If the level of technological development and the level of environmental well-being, which allows the population to be provided with high-quality and nutritious food, are sufficiently close, then the country is in a stable (equilibrium) zone. At the same time, the criterion within the *TD* and *ES* values of no more than 23 units should be observed.

In other words, there is potential for sustainable, balanced development. In this case, the country is able to modify existing technologies to prevent a decline in the efficiency of life support systems.

If the difference between *TD* and *ES* is in the range of 23–34 units, the country is in an unstable (slightly unbalanced) situation. This can be described as the limit of balanced food security. In this case, industrial technologies need to be changed and agricultural areas need to be intensively restored.

When discussing food security based on balanced development, the main factors are usually taken into account. Secondary indicators are ignored. Naturally, this limits the assessment system, but it creates specific baseline characteristics for comparative analysis and identification of development trends. In particular, thanks to this system, decision-makers responsible for the economic development of the region and determining the relevant policy have a multifaceted information base. This allows not only to maintain isolated economic, social and other factors of development, but also to make informed management decisions.

Ensuring balanced development of food security consists of achieving two main goals: reducing environmental degradation and increasing the level of technological development. To this end, for example, various options from the following four regional (macro) strategies can be used [18]:

- *t1* – growth in the level of influence of new technologies (Technology Application in the Region – *TAR*);
- *t2* – growth in the technological impact on food security (Technology Impact on the Region – *TIR*);
- *e1* – reduction in man-made pressure on agricultural land (*TL*);
- *e2* – reduction in man-made pollution of agricultural land (*TP*).

Based on data collected between 2014 and 2024, weighting coefficients were calculated for the main agricultural products – wheat grain and beef. Production was studied in the specified areas, with an assessment of the significance of each product in the total volume of food produced. The areas under study were examined in order of increasing technogenic load and intensifying food security imbalance. The results were processed using Statistica software. Intermediate calculations and summaries were performed using Microsoft Excel. The calculation of basic indices with the necessary visualization was implemented using an application written in the Python programming language.

3. Results and Discussion

3.1. Definition of aggregates and sub-indices for model construction

Based on the data collected for the period 2014–2024, test calculations of indicators and indices were performed. The results of the calculation of aggregates and sub-indices of the *TEDR* index are presented in Table 4, and for the *ETO* index – in Table 5.

The total values of the above indicators, as well as the *TEDR* and *ETO* indices, are presented in Table 6.

Table 4

Calculation of aggregates and sub-indices of the *TEDR* index

Regions	*W*	*M*	*GD*	*F*	*P*	*US*
North Kazakhstan Region	0.48	0.22	14.88	0.41	0.45	17.47
Kostanay Region	0.49	0.10	13.32	0.24	0.45	14.74
Akmola Region	0.46	0.23	14.74	0.41	0.70	22.43
Regions	*E*	*I*	*DF*	*C*	*S*	*PR*
North Kazakhstan Region	0.56	0.2	15.80	0.01	0.01	7.56
Kostanay Region	0.52	0.05	13.07	0.01	0.01	7.56
Akmola Region	0.69	0.45	23.09	0.15	0.01	8.69

Table 5

Calculation of aggregates and sub-indices of the *ETO* index

Regions	*E*	*D*	*TL*	*G*	*V*	*A*	*B*	*TP*
North Kazakhstan Region	0.45	0.08	12.52	0.40	0.44	0.45	0.65	6.96
Kostanay Region	0.38	0.15	12.55	0.35	0.44	0.15	0.30	3.45
Akmola Region	0.70	0.27	19.47	0.58	0.31	0.9	0.38	8.74

Table 6

Total values of the *TEDR* and *ETO* indices

Regions	*TAR*	*TIR*	*TEDR*	*TL*	*TP*	*ETO*	Weight*	*TEDR* with weigh	*ETO* with weigh
North Kazakhstan Region	32.35	23.36	11.5	12.52	6.96	6.98	1.04	11.96	7.26
Kostanay Region	28.06	20.63	12.7	12.55	3.45	9.21	1.03	13.08	9.48
Akmola Region	37.17	31.78	23.05	19.47	8.74	22.5	1.05	24.20	23.62
Total	–	–	–	–	–	–	3.15	49.24	40.36

Note: * – aggregated weight coefficient of influence of wheat grain and meat processing enterprises directly for each region

According to the *TEDR* index, the Akmola region is at the third (synergistic) level of technological development. The other regions are at the first (extensive) level of technological development. At the same time, the Kostanay and North Kazakhstan regions are at the lower end of the first level in terms of their development. This indicates that good preservation of agricultural land with the possibility of obtaining environmentally friendly products.

According to the *ETO* index, the Akmola region is at the second (critical) level of man-made environmental degradation in the region.

This is due to the rapid pace of industrial development and active human intervention in connection with the development of tourism and the recreational business. The remaining regions are close to the first zone with a low degree of environmental degradation.

3.2. Model of balanced development of food security in the regions under study

Based on model (3) using the weighted average value of the *EO* indices, it is possible to introduce the environmental well-being index *ES* for the regions under study

$$ES=\frac{1}{EO}\cdot 10^3, \qquad (4)$$

which will enable the technological development index of these same territories to be expanded:

$$SUTED=e^{-x^2}\cdot b,$$
$$x=(TD-ES)^2\cdot c, \qquad (5)$$

where *b* and *c* – aggregated scale coefficients of basic products in ensuring food security within the boundaries of the studied territory.

Taking into account the changes (4) in model (3), as well as the balance model (5), it can be noted that if the difference between *TD* and *ES* is in the range of 23–34 units, then the studied area is in an unstable (weakly balanced) situation, which is defined as the "limit of effective development". In this area, technological development processes, although deviating from equilibrium, do not do so to an extent that would significantly affect food security in the territory under study. These processes only modify their direction and impact on ensuring balanced development. However, further food security in this case can only be ensured through the use of modern, highly efficient technologies for the recovery of agricultural land.

If the levels of technological development and environmental well-being differ so significantly that the SUTED value is below the inflection points (Fig. 3), this indicates that the area under study is in a changing (unbalanced) situation.

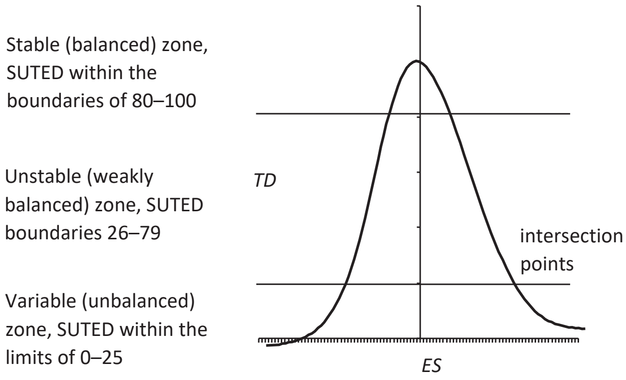

Fig. 3. Exponent of the stability level SUTED

In the first case – when *TD* > *ES* – it is about talk about the irrational use of natural resources and, accordingly, agricultural land. Technological development does not take into account the potential of the environment, does not adapt to it, and ceases to be a factor of progress, excessively suppressing the environment. In this case, decision-makers need to make targeted efforts to increase the value of *ES*.

When *TD* < *ES*, the study area is characterized by a high level of agricultural land conservation with relatively low anthropogenic impact on the environment. An environment with such resource potential has good prospects for enhancing technological development in agriculture to ensure food security.

The second situation looks much more attractive than the first, as it allows for balanced development of food security. According to the criteria studied, the *TD* < *ES* indicators for the Kostanay and North Kazakhstan regions are approximately the same, at 78.1 and 78.3, respectively. This is the upper third of the slightly unbalanced zone, and these regions have every opportunity to grow environmentally friendly food products.

For the Akmola region, *TD* > *ES*, the indicator is 24.7. The indicator is not threatening. However, it indicates that it is necessary to introduce more modern technologies for the restoration of agricultural land after technogenic impacts.

3.3. An example of implementing an approach to forming a model of balanced food security development in conditions of technogenic stress

As an example, let's consider three regions of the Republic of Kazakhstan – West Kazakhstan, Kyzylorda and Aktobe. These areas are developing both industrial production and agriculture, while at the same time experiencing man-made pressure on the environment. Let's consider strategies *t1*, *t2*, *e1*, and *e2* for grain and meat for these regions.

To determine the effectiveness of these strategies, *TAR*, *TIR*, *TL*, *TP*, *TEDR*, and *ETO* indices are used. The necessary coefficients are calculated based on indicators for the industrialized regions of the Republic of Kazakhstan (averaged). The aggregate weight coefficient of influence of wheat grain and meat processing enterprises for each region is taken to be equal to 1.1 for all regions.

To this end, at the regional level, the coefficients of aggregate efficiency of possible target strategies for technological development – $k = TEDR/TD \leq 1$, and environmental well-being – $q = ETO/ES \leq 1$, are first calculated. By multiplying these coefficients by the values of the corresponding sub-indices *TAR*, *TIR*, *TL*, and *TP*. Let's obtain estimates of the impact of the above strategies on the current situation in the areas of food security: $Ak = k \cdot TAR$, $Ik = k \cdot TIR$, $Lq = q \cdot TL$, $Pq = q \cdot TP$. An example of the calculation is presented in Table 7.

Table 8 presents an assessment of the impact of target strategies in each area.

Based on the calculated values obtained, it is possible to compare the effectiveness of strategies that enable balanced development of food security (Table 9).

Table 7

Efficiency coefficients by area

Regions	Indices of technological development and environmental well-being		Indices		Overall effectiveness coefficients for target strategies	
	TD	*ES*	*TEDR*	*ETO*	*k*	*Q*
North Kazakhstan Region	29.26	46.80	27.86	19.48	0.95	0.42
Kostanay Region	29.26	46.80	38.79	20.7	1.0	0.44
Akmola Region	29.26	46.80	34.48	28.21	1.0	0.6

Table 8

Assessment of the impact of target strategies

Targeted strategies	Sub-indices	Coefficients		The degree of influence of the regional target strategy on food security	
		k	*q*		
1	2	3	4	5	6
North Kazakhstan Region					
t1. The growing impact of new technologies	*TAR* = 32.35	0.95	–	*Ak*	30.7
t2. The growing impact of technology on food security	*TIR* = 23.36	0.95	–	*Ik*	21.2
t3. Combining strategies *t1* and *t2*	–	–	–	–	51.9
e1. Reducing the anthropogenic load on agricultural land	*TL* = 12.52	–	0.42	*Lq*	5.26
e2. Reduction of man-made pollution of agricultural land	*TP* = 6.96	–	0.42	*Pq*	2.9
e3. Combining strategies *e1* and *e2*	–	–	–	–	8.16
Kostanay Region					
t1. The growing impact of new technologies	*TAR* = 33.51	1.0	–	*Ak*	33.51
t2. The growing impact of technology on food security	*TIR* = 44.07	1.0	–	*Ik*	44.07

Continuation of Table 8

1	2	3	4	5	6
t3. Combining strategies *t1* and *t2*	–	–	–	–	77.57
e1. Reducing the anthropogenic load on agricultural land	*TL* = 17.62	–	0.44	*Lq*	7.75
e2. Reduction of man-made pollution of agricultural land	*TP* = 3.08	–	0.44	*Pq*	1.36
e3. Combining strategies *e1* and *e2*	–	–	–	–	9.11
Akmola Region					
t1. The growing impact of new technologies	*TAR* = 37.17	1.0	–	*Ak*	37.17
t2. The growing impact of technology on food security	*TIR* = 31.78	1.0	–	*Ik*	31.78
t3. Combining strategies *t1* and *t2*	–	–	–	–	68.95
e1. Reducing the anthropogenic load on agricultural land	*TL* = 19.47	–	0.6	*Lq*	11.68
e2. Reduction of man-made pollution of agricultural land	*TP* = 8.74	–	0.6	*Pq*	5.24
e3. Combining strategies *e1* and *e2*	–	–	–	–	16.92

Table 9

Assessment of strategy effectiveness

North Kazakhstan Region					
The degree of impact of regional strategies on food security		The degree of impact of “environmental” strategies			Total
		E1	*E2*	*E3*	The most effective strategies (in descending order) are: *T2* combined with *E3*; *T2* combined with *E1*; *T2* combined with *E2*
		5.26	2.9	8.16	–
T1	30.7	25.44	27.8	22.54	–
T2	21.2	15.94	18.3	13.04	
T3	51.9	46.64	49.0	43.74	
Kostanay Region					
The degree of impact of regional strategies on food security		The degree of impact of “environmental” strategies			Total
		E1	*E2*	*E3*	The most effective strategies (in descending order) are: *T2* combined with *E3*; *T2* combined with *E1*; *T2* combined with *E2*; *T1* combined with *E3*; *T1* combined with *E1*
		4.27	1.17	5.44	–
T1	23.29	19.02	22.12	17.85	–
T2	17.12	12.85	15.95	11.68	
T3	40.41	36.14	39.24	34.97	
Akmola Region					
The degree of impact of regional strategies on food security		The degree of impact of “environmental” strategies			Total
		E1	*E2*	*E3*	*T2* strategies are most effective when combined with *E3*
		11.68	5.24	16.92	–
T1	37.17	25.49	31.93	20.25	–
T2	31.78	20.1	26.54	14.86	
T3	68.95	57.27	63.71	52.03	

Thus, with the help of multifaceted macroeconomic strategies, it is possible to ensure the balanced development of food security as a separate area, in a particular region, or in the country as a whole. These strategies are mainly based on the compilation of economic balances and technological impact. The study expands on the work [8] by providing a new approach to balance analysis of the development of production sectors and significantly increasing the priority of agricultural manufacturers.

This study provided radically new results compared to those presented in [11], as the results are based on statistical reports and financial indicators for a period of 10 years. The results also show that, unlike in [14], there is no need to make changes to biocenoses that would further increase technogenic and anthropogenic loads. It is sufficient to rationally balance the use of modern production and agricultural technologies.

The proposed indices characterize the state of affairs at a given point in time and, from this point of view, will be static when describing sustainable development processes. This allows, unlike in [15], this approach to be applied more broadly, adapting it to the study of food security issues in any country or region.

This allows to expand the scope of the work [5–7], agreeing with the authors. The modern economy requires different methods of describing the "people – industrial production – environmental impact" system when considering the challenges of achieving sustainable food security.

The limitations of the study are the selected number of balanced development factors. The main focus is on environmental factors in agricultural production. In particular, these are factors characterizing the anthropogenic load on agricultural land. Other balanced development factors are taken as constant values.

One of the disadvantages of the study is that the model uses only two weighting coefficients for wheat grain and beef. Each region and each country has its own priorities in ensuring food security. Therefore, a comprehensive model should take into account all priority areas of agricultural production.

Such research may also be of interest to Ukraine in wartime conditions. This model can be used to repurpose technologies in areas not affected by military operations for the purposes of balanced development and ensuring sustainable food security.

Further research on this topic could focus on analyzing the dynamics of balanced food security development processes depending on external, often insurmountable factors. Such analysis would enable the creation of reserves in case of natural disasters, which would make states and society more resilient.

4. Conclusions

1. The work calculated the aggregates and sub-indices necessary for building the model. A period of 10 years was selected for the study. Test calculations of indicators and indices were performed using statistical data for the period. It was determined that, based on the *TEDR* index value of 23.05, the Akmola region is at the third level of technological development. The Kostanay (13.7) and North Kazakhstan (11.5) regions are at the lower end of the first level of technological development. This indicates good preservation of agricultural land with the possibility of obtaining environmentally friendly products. According to the *ETO* index, the Akmola region is at the second (critical) level of technogenic oppression of the region's environment. This trend is the result of the active development of industrial production and tourism.

2. A model of balanced food security development was created for the regions under study. Aggregated scale coefficients for wheat grain and cattle meat were introduced into the basic Technological Development model. These products are key to ensuring food security within the regions under study and for Kazakhstan as a whole. The changes that can be made using the constructed model allow for the manipulation of various data, simulating a situation of balanced food security development. According to the criteria studied, the indicators for the Kostanay and North Kazakhstan regions are approximately the same, at 78.1 and 78.3, respectively. This is the upper third of the slightly unbalanced zone, and these regions have every opportunity to grow environmentally friendly food products. For the Akmola region, the indicator is 24.7. The indicator is not threatening, but it indicates that it is necessary to introduce more modern technologies for the restoration of agricultural land after man-made impacts.

3. An example of the practical implementation of the proposed approach is presented. Three regions of the Republic of Kazakhstan are considered as examples: North Kazakhstan Region, Kostanay and Akmola. Both industrial production and agriculture are actively developing in these regions. However, the environment in these regions is under significant anthropogenic pressure. Based on the developed model, assessments of balanced development strategies were carried out according to the criterion of ensuring food security. As a result, evidence was obtained of the integration of various projects for the rational use of agricultural resources.

The proposed approach can be used to analyses the balanced development of regions with the aim of intensifying food production. This approach can also be applied in general to monitor food security programmes in various countries around the world.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Mondal, P., DeFries, R., Clark, J., Flowerhill, N., Arif, Md., Harou, A. et al. (2021). Multiple cropping alone does not improve year-round food security among smallholders in rural India. *Environmental Research Letters, 16 (6)*, 065017. https://doi.org/10.1088/1748-9326/ac05ee
2. Kent, K., Brooks, C., Attuquayefio, T., Ewald, A., Morrison, N., Alhassani, G. et al. (2025). Participation in a community-based food cooperative impacts self-reported food security status and dietary intake in Australian adults. *Appetite, 212*, 108030. https://doi.org/10.1016/j.appet.2025.108030
3. Sultan, Md. T., Mahmud, U., Khan, Md. Z. (2023). Addressing soil salinity for sustainable agriculture and food security: Innovations and challenges in coastal regions of Bangladesh. *Future Foods, 8*, 100260. https://doi.org/10.1016/j.fufo.2023.100260
4. Westerveld, J. J. L., van den Homberg, M. J. C., Nobre, G. G., van den Berg, D. L. J., Teklesadik, A. D., Stuit, S. M. (2021). Forecasting transitions in the state of food security with machine learning using transferable features. *Science of The Total Environment, 786*, 147366. https://doi.org/10.1016/j.scitotenv.2021.147366
5. Aigarinova, G. T., Akshatayeva, Z., Alimzhanova, M. G. (2014). Ensuring Food Security of the Republic of Kazakhstan as a Fundamental of Modern Agricultural Policy. *Procedia – Social and Behavioral Sciences, 143*, 884–891. https://doi.org/10.1016/j.sbspro.2014.07.511
6. Lazzat, Y., Aigerim, O., Daniya, N. (2014). The Ecological and Legal Aspects of Ensuring the Food Security of the Republic of Kazakhstan Under the Transition to a "Green" Economy. *Procedia – Social and Behavioral Sciences, 143*, 971–975. https://doi.org/10.1016/j.sbspro.2014.07.536
7. Malyarenko, O., Kushebina, G. (2022). Sustainable development of the agro-industrial complex of Kazakhstan as the basis of the country's food security. *Agrarian Bulletin of The, 216 (1)*, 86–91. https://doi.org/10.32417/1997-4868-2022-216-01-86-91
8. Yessymkhanova, Z., Niyazbekova, S., Tochieva, L., Goigova, M., Varsin, V., Varaksa, N. et al. (2021). Livestock products of households in ensuring food security in Kazakhstan. *E3S Web of Conferences, 284*, 02020. https://doi.org/10.1051/e3sconf/202128402020
9. *Varieties and Technologies*. University of Agricultural Sciences Bangalore. Available at: https://www.uasbangalore.edu.in/en/varieties-and-technologies/
10. Duisenbekuly, A., Kulbay, B., Bigeldiyeva, Z., Zhakipbekova, D., Daurbayeva, M. (2024). Food security in Kazakhstan and Azerbaijan: Challenges and strategies for economic and sustainable development. *International Journal on Food System Dynamics, 15 (3)*, 267–277. https://doi.org/10.18461/ijfsd.v15i3.k5
11. Eicher-Miller, H. A., Wright, B. N., Tooze, J. A., Craig, B. A., Liu, Y., Bailey, R. L. et al. (2022). Evaluating a Food Pantry-Based Intervention to Improve Food Security, Dietary Intake, and Quality in Midwestern Food Pantries. *Journal of the Academy of Nutrition and Dietetics, 122 (11)*, 2060–2071. https://doi.org/10.1016/j.jand.2022.02.016
12. Burke, M., Cabili, C., Berman, D., Forrestal, S., Gleason, P. (2021). A Randomized Controlled Trial of Three School Meals and Weekend Food Backpacks on Food Security in Virginia. *Journal of the Academy of Nutrition and Dietetics, 121 (1)*, 34–45. https://doi.org/10.1016/j.jand.2020.10.026

13. Toiba, H., Rahman, M. S., Nugroho, T. W., Priyanto, M. W., Noor, A. Y. M., Shaleh, M. I. (2024). Understanding the link between climate change adaptation and household food security among shrimp farmers in Indonesia. *Marine Policy, 165*, 106206. https://doi.org/10.1016/j.marpol.2024.106206
14. Ofoedu, C. E., Bozkurt, H., Mortimer, J. C. (2025). Towards sustainable food security: Exploring the potential of duckweed (Lemnaceae) in diversifying food systems. *Trends in Food Science & Technology, 161*, 105073. https://doi.org/10.1016/j.tifs.2025.105073
15. Nchanji, E. B., Chagomoka, T., Bellwood-Howard, I., Drescher, A., Schareika, N., Schlesinger, J. (2023). Land tenure, food security, gender and urbanization in Northern Ghana. *Land Use Policy, 132*, 106834. https://doi.org/10.1016/j.landusepol.2023.106834
16. Alhelou, H. H., Amani, A. M., Sajjadi, S. S., Jalili, M. (2022). *Electric Transportation Systems in Smart Power Grids*. CRC Press. https://doi.org/10.1201/9781003293989
17. *Bureau of National statistics*. Agency for Strategic planning and reforms of the Republic of Kazakhstan. Available at: https://stat.gov.kz/
18. Hull, R. N., Barbu, C.-H., Goncharova, N. (Eds.) (2007). Strategies to enhance environmental security in transition countries. *NATO Science for Peace and Security Series C: Environmental Security*. Netherlands: Springer, 429. https://doi.org/10.1007/978-1-4020-5996-4
19. *The Sustainable Development Goals Report 2023: Special Edition* (2023). The Sustainable Development Goals Report, 80. https://doi.org/10.18356/9789210024914

Zhanar Amangeldiyeva, *PhD Student, Department of Economics and Entrepreneurship, Non-Profit Joint-Stock Company "L. N. Gumilyov Eurasian National University", Astana, the Republic of Kazakhstan, ORCID: https://orcid.org/0000-0001-5934-237X*

Raissa Baizholova, *Doctor of Economic Sciences, Department of Economics and Entrepreneurship, Non-Profit Joint-Stock Company "L. N. Gumilyov Eurasian National University", Astana, the Republic of Kazakhstan, ORCID: https://orcid.org/0000-0003-3873-6753*

✉ ***Danagul Tleuzhanova,*** *PhD, Department of Accounting and Finance, NCJSC "S. Seifullin Kazakh Agro Technical Research University", Astana, the Republic of Kazakhstan, e-mail: d.tleuzhanova@kazatu.edu.kz, ORCID: https://orcid.org/0000-0001-6098-2147*

Gulzhan Mukasheva, *Department of Accounting and Finance, NCJSC "S. Seifullin Kazakh Agro Technical Research University", Astana, the Republic of Kazakhstan, ORCID: https://orcid.org/0000-0002-3020-6144*

Dauren Sarzhanov, *PhD, Cabinet for the Development and Implementation of Educational Programs, Academy of Public Administration under the President of the Republic of Kazakhstan, Karaganda, the Republic of Kazakhstan, ORCID: https://orcid.org/0000-0002-7250-1029*

Talgat Zhakupov, *PhD, Department of Thermal Power Engineering, Non-Profit Joint-Stock Company "L. N. Gumilyov Eurasian National University", Astana, the Republic of Kazakhstan, ORCID: https://orcid.org/0000-0002-9725-0262*

✉ *Corresponding author*