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A logistics model of sustainable food supply of the region

Abstract. *Introduction.* The problem of sustainable food supply is connected with the optimisation of the distribution of food flows and determined by the quantity of food in terms of per capita consumption, energy value and availability of nutrients. *The purpose* of the article is to develop a logistics model of sustainable food supply in the region and test it on the example of Saratov region of Russia. *Methods.* In the process of economic-mathematical modelling, the authors used econometric and logistics methods. *Results.* The article describes the authors' approach to building local food systems. A two-level model of demand for food products was substantiated. The conducted calculations of the indicators of sustainability of the local food systems of Saratov region for the most important types of food products show that three local food systems centred in towns of Kalininsk, Novouzensk and Ershov are fully food self-sufficient. The local food systems of the towns of Volsk, Balashov and Balakovo have difficulties in the matters of self-sufficiency in meat products; and the local food systems of the city of Saratov and the town of Engels have to import meat and milk in order to have quality and sustainable provision of the population with such products. *Conclusions.* The use of the logistics approach allows us to develop a universal algorithm for the assessment of the overall sustainability of food supply of the region, consider the impact of transportation costs on food consumption by the population, substantiate the rational logistics and delivery routes of agricultural production for its further processing, which will increase the overall sustainability of food supply in a particular region.
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Логістична модель стійкого продовольчого забезпечення регіону

Анотація. У статті запропоновано методику оцінки стійкості продовольчого забезпечення, що передбачає структурування території регіону на окремі локальні продовольчі системи з подальшим аналізом кожної з них за критеріями самозабезпеченості продовольством, і викладено авторський підхід до формування локальних продовольчих систем. Авторами статті було обґрунтовано дворівневу модель попиту на продовольчі товари та запропоновано економіко-математичну модель стійкості продовольчого забезпечення з урахуванням раціональних логістичних маршрутів доставки сільськогосподарської сировини в конкретні населені пункти регіону для її подальшої переробки. Виявлено, що використання логістичного підходу дозволяє виробити універсальний алгоритм оцінки рівня стійкості продовольчого забезпечення окремих регіонів, урахувати вплив транспортних витрат на споживання продовольства населенням.
Ключові слова: локальні системи; продовольчі потоки; стійкість; збалансованість; Саратовська область; логістика; сільськогосподарська продукція; продовольча безпека.

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Логистическая модель устойчивого продовольственного обеспечения региона

Аннотация. В статье изложен авторский подход к формированию локальных продовольственных систем и обоснована двухуровневая модель спроса на продовольственные товары. Авторами разработана экономико-математическая модель устойчивости продовольственного обеспечения, а также предложены рациональные логистические маршруты доставки сельскохозяйственного сырья в населенные пункты региона для его последующей переработки. Выявлено, что использование предложенного логистического подхода позволяет выработать универсальный алгоритм оценки уровня устойчивости продовольственного обеспечения регионов с учетом влияния транспортных затрат.

Ключевые слова: локальные системы; продовольственные потоки; устойчивость; сбалансированность; Саратовская область; логистика; сельскохозяйственная продукция; продовольственная безопасность.

1. Introduction

In modern conditions of the development of regional economy, the issues of achievement of sustainability based at balanced supplies on the food market are becoming increasingly important. Therefore, the sustainability of food supply may act as an optimal criterion focused on the effective development of agricultural producers at better meeting the needs of population in quality and adequate nutrition.

2. Brief Literature Review

From a regional perspective, there exist different methodological approaches to assess the balance of food supply, the main of which are: the multicriteria approach and a combination of mathematical programming methods [1]; cluster analysis [2]; determination of the ratio of effective demand and supply in the food market [3]; comparison of the level of manufacture and consumption of agricultural products [4]; conformity assessment of the price level in relation to the real value of food products [5]; determination of the possibility of achieving the criteria of the balanced nutrition by the population [6]. In the world practice, traditional characteristics of the food market, which are the capacity, the potential, the degree of saturation, the level of self-sufficiency, competition, the degree of import penetration, etc., are used to assess the sustainability of food supply. However, ways of food distribution, which are social and economic in origin, also have significant influence [7-8].

Modern regional development is closely connected with the concept of economic instability and new technical knowledge [9]. The process of sustainability provision is inextricably linked with the rational use of resources of the food system and the need to reduce costs and improve economic efficiency of management [10]. One of such mechanisms, according to the authors, is the formation of «Local food systems» and «Alternative agro-food networks» operating within their framework. Both concepts are associated with the creation of conditions for fast (preferably without intermediaries) access of consumers to local food and are considered from the perspective of new models of interaction between producers, suppliers and consumers, based, on the one hand, on individual socio-economic, natural-climatic and other characteristics of specific territories and, on the other hand on the desire to avoid displacement of local food producers from the market [11-12], their support in order to achieve a higher level of self-sufficiency and reducing dependence on imports [13]. The operation of alternative agro-food networks is connected with the boundaries of the geographical area ranging from 50 km to 100 km from the point of their production [14]. They are focused on specific food product sales (agricultural fairs, specialised food stores, direct purchase from producers, targeted supply of food, etc.), including the use of «short food supply chains», which allows to provide farmers with more favourable conditions for management [15-16].

Along with this, it is impossible to organise food supply without taking into account the provisions of the basic world theories of regional development, such as the core-periphery model suggested by John Friedman (1966) [17] and the theory of competitive advantages by P. Krugman (1991) [18], under which large regional centres through the use of competitive factors reducing the economic costs will always take in resources from the periphery. In addition, it is the urban population who primarily supports the effective demand for food.

It is important to take into account aspects such as the volumes of production, the features of the market, as well as, its infrastructure and the operators' actions [19]. The city has a direct impact on the farmer as it accumulates almost all available opportunities to replenish the inventory and equipment, purchase household and industrial products, attract credit resources, etc. All this gives grounds to consider large urban communities in local food systems to be the main centres where infrastructure facilities for processing agricultural products and food consumption [20- 22], along with gross income, investment capital, skilled labour and scientific potential, are concentrated [23-24].

3. The purpose of the article is to develop a logistics model of food supply of the region and test it on the example of Saratov region.

4. Results

Timely sales and payments for manufactured agricultural products are most important for regional agriculture, as these conditions have the most significant stimulating effect on agricultural production, provide a basis for stability and give the farmer confidence in the future.

The vast majority of manufactured agricultural products are sold by farmers to processing companies. Agricultural producers are interested in the opportunity to sell their products in a short period of time; also they desire to avoid the influence of external adverse factors, to minimise their expenses and to quickly and efficiently prepare for the next agricultural season. These are large processing companies which are able to accumulate substantial stocks of food raw materials, to efficiently process non durable products and to carry out quick payments to farmers, which optimally matches all the mentioned criteria.

A general scheme of operation of the local food systems is shown in Figure 1.

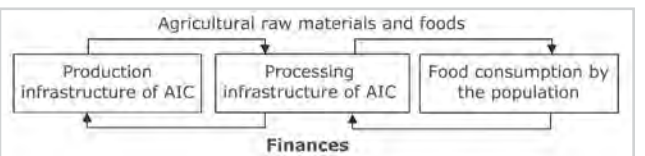

Fig. 1: **General scheme of the local food systems operation**
Source: Compiled by the authors

In practice, coordination of economic and social interests of various actors in the food market is carried out through the pricing mechanism, which is directly connected with the transportation costs of the delivery of raw agricultural products to processing sites and the delivery of finished food products to the consumer.

The trade and transport infrastructure also has a direct impact on this process, the degree of development of which determines not only the possibility of selling agricultural products, but also the feasibility of farming. The data presented in Table 1 and Table 2 clearly confirm that when the trade and transport infrastructure is of sufficient quality, this can be viewed as an additional factor that improves farmers' motivation and interest in increasing their labour productivity.

From the perspective of agricultural producers, transportation costs affect the purchase price and reduce it. However, farmers are not interested in self-storage of manufactured products until the favourable market conditions are created. As a consequence, farmers will falways be aimed at developing nearby markets to minimise losses. From the perspective of the consumer, transportation costs also affect the consumer price in terms of increasing it, which leads to a reduction in the volume of food consumption. In practice, consumers focus on purchasing cheaper local products, so as not to limit their consumption. It is also worth noting that there is an objective process of expanding the influence of one or another large centre on the adjacent areas because of the fact that the more the final consumption of food products is, the less important the transportation costs are, as they are compensated for by the increasing selling price.

Tab. 1: **Coefficient of quality of trade and transport infrastructure of the individual EU countries and Russia**

Country	1 = low, 5 = high		
	2010	2012	2014
Germany	4.34	4.26	4.32
France	4.00	3.96	3.98
Italy	3.72	3.74	3.78
Spain	3.58	3.74	3.77
Russia	2.38	2.45	2.59

Source: http://data.trendeconomy.ru/indicators/Logistics_Performance_Index_Quality_Of_Trade_And_Transportrelated_Infrastructure_Low_To_High/France?country=Germany,Italy,Russia,Spain

Tab. 2: **Average level of agricultural production in the regions of individual EU countries and Russia in current prices, EUR million**

Country*	Years						
	2010	2011	2012	2013	2014	2015	2016
Germany	2,876.6	3,361.8	3,428.4	3,608.6	3,495.1	3,202.4	3,201.5
France	2,620.2	2,809.1	2,945.3	2,853.2	2,891.8	2,891.3	2,699.1
Italy	2,407.9	2,623.2	2,716.6	2,875.9	2,709.6	2,760.2	2,645.1
Spain	2,374.7	2,409.6	2,467.8	2,592.0	2,587.8	2,675.8	2,753.3
Russia	725.9	970.6	965.3	1,115.8	1,127.7	888.9	-**

Note: * - The calculation is based on the administrative division of Germany into 16 lands, France into 26 regions, Italy into 20 regions, Spain into 17 autonomies, Russia into 83 regions.
** - The corresponding data are planned for publication by the State Statistics Committee of the Russian Federation in late 2017

Source: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&pcode=tag00102&language=en
http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/publications/catalog/doc_1138623506156

The transportation costs of the delivery of raw agricultural products to the processing sites will depend on the difference between the volume of regional agricultural production and the value of local consumption, as well as in the degree of remoteness of agricultural producers from the markets (Formula 1). This means that in order to minimise the producers' transportation costs, to a processing site agricultural products from the surrounding districts will be delivered primarily, and then from the more remote districts, until the total value of food flow fully meets the needs of urban community. Hence, in order to sell the remaining agricultural products, other markets should be sought for.

$$Tp1 = \sum(V1 - Vc) \times g \times L\,, \quad (1)$$

where:

$Tp1$ - transportation costs for the delivery of raw agricultural products from producers to processing sites;

$V1$ - sales of the manufactured agricultural products, thousand tons;

Vc - the production volume of the private subsidiary farms used by rural residents for personal consumption, thousand tons;

q - transportation costs of 1 kg of cargo per 1 km, RUR (Russian rubles);

L - the distance from the place of manufacturing of specific agricultural products to the nearest processing plant, km.

Transportation costs for the delivery of final products to the places of their sales are limited only by a maximum possible volume of consumption by residents in large urban communities and the scale of displacement within the city, which is the centre of local food system (Formula 2).

$$Tp2 = V2 \times g \times Ln\,, \quad (2)$$

where:

$Tp2$ - transportation costs for the delivery of finished food products to the consumer;

$V2$ - the volume of food consumption;

Lin - the scale of displacement of food within the local food system.

Unlike the existing approaches, the proposed approach to the determination of the degree of influence of transportation costs on the volume of the food consumed in the region considers the deviation from the classical «supply and demand» scheme and the use of a two-level analysis of the demand for agricultural products. In the first case, it is a fundamental demand for agricultural products generated by agricultural processing companies. In the second case it is the demand of the population for the products of the processing enterprises.

It makes sense to present the sustainability of food supply in the form of a balanced condition of production and consumption of food of the (j) nomenclature in (i) of the local food system, estimated from the position of the purchase price and the selling price, as well as producers' transportation costs for the delivery of raw agricultural products to processing sites and the delivery of finished food products to the consumer.

In these conditions, the overall sustainability (balance) of food systems of the region will be characterised by the degree of customer's satisfaction with food supply (economic, physical accessibility, quality, etc.) and the degree of agricultural producers' satisfaction with the result of their own economic activity (profitability, profit earning capacity, etc.). Both criteria in this model are expressed as the difference between the total estimation of the volumes of produced and consumed foods and transportation costs for their delivery:

$$S1ij - Tp1ij = S2ij - Tp2ij\,, \quad (3)$$

where:

$S1\,ij$ - the volume of produced foods;

$S2\,ij$ - the volume of consumed foods.

Consequently, the following conditions act as limitations in the economical-mathematical model:

$$\begin{cases} V1 \geq V2 \\ V2 \geq Nrat \end{cases}, \quad (4)$$

where:

$V1$ - the manufacturing volume of agricultural production;

$V1 \geq V2$ - the opportunity of having total self-sustainment of a specific region in agricultural products of its own production;

$V1 \geq Nrat$ - the level of nutrition of the population which is not below the rational standard of consumption.

It should be kept in mind that the rural population traditionally seeks to achieve self-sustainment in food products. Therefore, processing companies are focused on the demand of the residents of large urban communities and the surrounding areas, who do not run private subsidiary farms. That is, the volume of consumed agricultural products $V2\,ij$ (Formula 5) is limited by the size of the urban population.

$$V2ij = Ncityi \times Rj\,, \quad (5)$$

where:

$Ncityi$ - the number of the urban population in the i local food system, people;

Rj - the rate of consumption j of food product, kg/year/person.

Thus, the determination of the value of the production volume of private subsidiary farms used by rural residents for personal consumption will be directly related to the purchase price of $c1$, because the actual sales do not happen there.

Based on the proposed method of determining sustainability by setting the difference between the total value of the volumes of produced and consumed foods and transportation costs for their delivery, under the conditions of balance the point of sustainability of the food system will tend to the figure of one:

$$Bij = \frac{S2ij - Tp2ij + Tp1ij + Sownij}{S1ij} \rightarrow 1\,, \quad (6)$$

where:

Bij - the indicator of sustainability of the food supply system including transportation costs.

If the calculated value $Bij < 1$, then the production component of food supply dominates in the district, if $Bij > 1$, the consumer component is prevalent. It is expedient to develop processing capacities of the agricultural sector, where the consumer component is greater than the one of production, as there is a financial basis for the activity of agricultural processing companies, i.e. an effective demand of the population for food. Otherwise, additional ways of sales of agricultural products should be sought.

Thus, the final formula determining the sustainability of the local food system including transportation costs takes the following form:

$$Bij = \frac{(Ncityij \times Rij \times c2ij - Ncityij \times Rij \times gij \times Linij) + (\sum(V1ij - Vownij) \times gij \times Lij) + Nruralij \times Rij \times c1ij}{V1ij \times c1ij}\,. \quad (7)$$

The analysis of the spatial logistic component of the proposed model of the sustainability of food supply allowed structuring the territory of the region into 8 main local food systems with their centres in the towns of Saratov, Volsk, Kalininsk, Balashov, Engels, Balakovo, Novouzensk and Ershov.

The conducted calculations of the indicators of sustainability of the local food systems in the Saratov region based at data of 2016 for the most important types of food products are presented in Table 3.

The calculations show that three local food systems centered in towns of Kalininsk, Novouzensk and Ershov are fully food self-sufficient and are able to guarantee the people high quality food through their own capabilities. The local food systems of the towns of Volsk, Balashov and Balakovo have difficulties in the matters of self-sufficiency in meat products; and the local food systems of the city of Saratov and the town of Engels have to import meat and milk in order to have quality and sustainable provision of the population with such products.

The comparative analysis of the manufactured and consumed foods allowed us to determine the volumes of deficient and excess foods relevant to the highlighted local food systems, while the analysis of the distance between them allowed us to substantiate rational logistic routes of the delivery of raw agricultural products to specific communities of the region for their further processing and identify the overall volume of intraregional food flows:

a) for bread and flour products: the additional transportation of raw products is not required within the region, the districts of the region are fully self-sufficient in cereals;

b) for meat and meat products: with the focus on the city of Saratov - from the local food systems of the town of Kalininsk (up to 3.9 thousand tons annually) and the town of Balashov (up to 5 thousand tons); with the focus on the town of Engels - from the local food systems of the town of Novouzensk (up to 7.7 thousand tons) and the town of Ershov (up to 7.9 thousand tons);

c) for milk and dairy products: with the focus on the city of Saratov - from the local food systems of the town of Volsk (up to 8.6 thousand tons), the town of Kalininsk (up to 18.6 thousand tons annually), the town of Balashov (up to 22 thousand tons), the town of Ershov (up to 112.6 thousand tons) and the town of Novouzensk (up to 88.9 thousand tons); with the focus on the town of Engels - from the local food systems of the town of Balakovo (up to 2 thousand tons) and the town of Novouzensk (up to 6.4 tons).

Transportation costs for the delivery of agricultural products to processing sites within the region were RUR 269.1 million, and they were RUR 251.7 million for the delivery to the places of retail sales and final consumption. The total transportation costs for agricultural producers and processors do not exceed 1.3% of the value of all manufactured food products. However, the calculations show that when delivering agricultural products over a distance of 89 km, transportation costs can be greater or equal to the total value of the transported food, which is a significant factor of influence on both the economic expediency of farming in specific communities of the region, and the final selling price of food products.

Tab. 3: **Calculation of the indicators of sustainability of local food systems in Saratov region by the most important types of food products**

Local food systems	Indicators of sustainability		
	Bread and flour products	Meat products	Dairy products
No. 1 centred in the city of Saratov	0.82	7.59	6.63
No. 2 centred in the town of Volsk	0.24	1.49	0.98
No. 3 centred in the town of Kalininsk	0.04	0.92	0.64
No. 4 centred in the town of Balashov	0.08	1.29	0.95
No. 5 centred in the town of Engels	0.43	4.40	1.37
No. 6 centred in the town of Balakovo	0.24	2.63	1.29
No. 7 centred in the town of Novouzensk	0.10	0.45	0.19
No. 8 centered in the town of Ershov	0.05	0.77	0.24

Source: Authors' elaboration

5. Conclusions

Based on the foregoing, it can be concluded that the use of the proposed approach in relation to different economic systems will make it possible to develop a universal algorithm for the assessment of the overall balance of food supply of the specific regions. Also, this technique enables estimating the level of sustainability of food supply in the region, to consider the impact

of transportation costs on food consumption, as well as to substantiate the rational logistics routes for the delivery of raw agricultural products to specific communities of the region for their further processing and to determine the overall volume of intraregional food flows that will provide the maximum coverage of the region area with quality food products of its own production and increase the sustainability of food supply of the region.

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