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Article

Forecast and Scenarios of Sustainable Development of Agriculture in the Republic of Karakalpakstan up to 2030

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Abstract: The article develops a forecast of agricultural development in the Republic of Karakalpakstan up to 2030. The forecast is based on official statistical data for 2015–2025 using two methods – scenario analysis of the real growth index and trend extrapolation by product type. Three scenarios are substantiated: inertial (3.7 % per year), baseline (4.0 %) and innovative (5.5 %). According to the calculations, under the inertial scenario the real volume in 2030 will be 1.20 times that of 2025, and 1.31 times under the innovative scenario. Trend analysis by product type shows the highest growth for eggs and potatoes (1.30–1.31 times) and virtually no growth for grain (0.99 times). The conditions and risks of implementing the scenarios are assessed.

Keywords: forecasting, scenario analysis, trend extrapolation, sustainable development, agriculture, Republic of Karakalpakstan, 2030, risk assessment.

1. Introduction

Forecast estimates are the main methodological tool in developing regional development programmes. They make it possible to substantiate target indicators, calculate resource requirements and compare alternative policy options. At the same time, the quality of forecasting depends directly on the reliability of the underlying data and on how well the chosen method suits the object of study.

Two typical errors occur in forecasting the agrarian sector. The first is the use of nominal value indicators: under high inflation, such a forecast significantly overstates growth. The second is limiting the analysis to a single scenario: this presents the forecast without uncertainty bounds and deprives the decision-maker of the opportunity to consider alternative options.

In the conditions of the Republic of Karakalpakstan, forecasting involves additional complexity. Agricultural results in the region depend strongly on year-to-year fluctuations in water supply, which causes high variation in statistical series. In addition, the sown area has been shrinking since 2022, which reduces the reliability of simple trend extrapolation.

The scientific literature treats agricultural sustainability as a combination of productive efficiency, environmental conservation and social well-being, so production growth alone cannot serve as a criterion of sustainable development [1]. Meeting growing demand without a proportional increase in environmental pressure requires higher resource-use efficiency, closing yield gaps and sustainable intensification rather than expansion of cultivated area [2], [3]. For Karakalpakstan these principles are tightly constrained by the environment. Large-scale irrigation expansion and unsustainable water

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management led to the Aral Sea disaster, with rising soil salinity and ecosystem degradation, and recovery requires coordinated water governance [4], [5]. Climate change adds uncertainty to river flows and irrigation demand in Central Asia and to agricultural productivity more broadly [6], [7]. The importance of water management, institutional reform, infrastructure and resilience to shocks is emphasized in the reports of international organizations [8]–[10].

Methodologically, time-series forecasting stresses data quality, model diagnostics and explicit treatment of forecast uncertainty [11], while scenario planning explores several plausible futures instead of extrapolating historical trends and is therefore well suited to environmentally vulnerable regions [12], [13]. At the policy level, the Uzbekistan–2030 Strategy [14] and the development initiatives of UNDP in the Aral Sea region [15] set priorities for water resource management, agricultural productivity, ecosystem rehabilitation and rural livelihoods, but their effect has to be assessed through measurable regional indicators and realistic assumptions.

Despite these contributions, three gaps remain. Forecasts of agricultural development often emphasize production indicators without integrating environmental constraints; trend-based methods may be insufficient when output is affected by structural environmental change; and quantitative regional forecasts for Karakalpakstan built on real rather than nominal values are scarce. The aim of this article is to fill these gaps by developing a forecast of agricultural development in the Republic of Karakalpakstan up to 2030 using scenario analysis of the real growth index and trend extrapolation by product type.

The practical value of a forecast is measured not by its accuracy but by the information it provides for decision-making. Long-term forecasts rarely come true as precise predictions, and this is natural. Their task is different: to show what outcome will be reached if existing trends continue and, on this basis, to substantiate whether intervention is or is not necessary.

For this reason, a scenario approach was chosen in this study. Scenarios are not competing predictions but trajectories reflecting the consequences of different policy options. The distance between them quantifies the impact of management decisions.

2. Materials and Methods

The forecast was carried out using two methods on the principle of mutual verification. The first method is scenario analysis based on the real growth index. The baseline is the real growth series for 2015–2025 calculated as the product of chain indices; this series is free of the price factor and reflects the actual dynamics of the sector.

Average annual growth rates calculated for different periods were used to substantiate the scenarios:

$$g = (I(t) / I(0))^(1/n) - 1$$

where I(t) and I(0) are the real index values in the reporting and base years, and n is the number of years. According to the calculations, the average rate is 3.70 percent for the last three years, 3.80 percent for the last five years and 4.01 percent for ten years. These values formed the basis of the inertial and baseline scenarios, respectively. A rate of 5.5 percent was adopted for the innovative scenario – it is close to the highest values of the last ten years and represents the level achievable if technological renewal and institutional reforms are implemented.

The second method is linear trend extrapolation by product type. For each product, a trend equation was constructed using the least squares method, and the coefficient of determination (R^2) was calculated. Where R^2 exceeds 0.90, the forecast is interpreted as reliable; between 0.70 and 0.90, as conditionally reliable; and below 0.70, only as an estimate indicating direction.

The limitations of the study are stated openly. First, the forecast assumes that the water supply regime will not change abruptly; an increase in the number of drought years would shift all scenarios downwards. Second, linear trend extrapolation does not take structural changes into account. Third, the 2025 data are preliminary and may be revised.

Using the two methods together allows mutual verification. If scenario analysis and trend extrapolation yield similar results, the reliability of the forecast increases; if there is a significant discrepancy, its cause must be identified. In this study, the growth coefficient to 2030 under both methods lies mainly within the range of 1.17–1.31, which indicates that the results are consistent with each other.

3. Results and Discussion

The real growth series forming the baseline of the forecast and the calculation results for the three scenarios are presented in Table 1.

Table 1. Forecast of the real volume of agricultural output, index (2015 = 100)

Scenario	Annual rate, %	2025 (base)	2026	2027	2028	2029	2030	2030/2025
Inertial	3.70	148.1	153.6	159.3	165.2	171.3	177.6	1.199
Baseline	4.01	148.1	154.1	160.3	166.7	173.4	180.3	1.217
Innovative	5.50	148.1	156.3	164.9	174.0	183.5	193.6	1.307

The table analysis first of all shows the magnitude of the gap between the scenarios. By 2030, the difference between the inertial and baseline scenarios amounts to only 2.7 index points – a practically insignificant magnitude. The innovative scenario, by contrast, diverges from the baseline by 13.3 points. Hence, fluctuations within existing trends do not significantly affect the result; a qualitatively different outcome can be achieved only through a one-and-a-half-fold increase in the growth rate.

The second observation concerns the dynamics of growth rates over time. The average rate is 4.01 percent for the ten-year period, 3.80 percent for the five-year period and 3.70 percent for the three-year period. The gradual decline in the rate confirms that the sources of extensive growth are being exhausted and justifies regarding the inertial scenario as the most likely option.

The third observation concerns the conditions of the innovative scenario. To achieve a rate of 5.5 percent, the source of additional growth must be clear. Expansion of the sown area cannot be such a source – it has been shrinking since 2022. Hence, the only real source is an increase in the output obtained from existing resources, i.e. higher water and land productivity. This links the innovative scenario directly to technological renewal.

The fourth observation concerns the interpretation of the forecast from the standpoint of sustainable development. A high growth rate is not in itself an indicator of sustainability. If 5.5 percent growth is achieved by increasing water consumption or depleting soil reserves, it will not be sustainable. For this reason, forecast indicators should be monitored together with resource indicators.

The graph analysis shows the relationship between the actual series and the forecast trajectories. The actual line for 2015–2025 is not smooth: in 2017–2018 an almost horizontal segment is observed (from 111.7 to 112.3), followed by a sharp rise in 2019. Such fluctuations are associated with year-to-year changes in water supply and weather conditions.

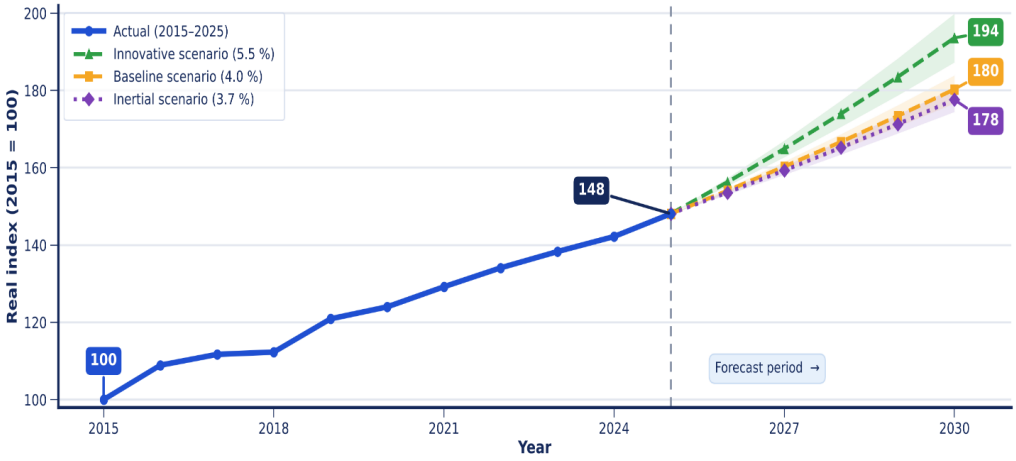


Figure 1. Real volume of agricultural output: actual dynamics and scenarios up to 2030

The forecast trajectories, in turn, are depicted as smooth lines. This is a methodological simplification of forecasting that should be taken into account when interpreting it: in practice, the dynamics of the next five years will also involve fluctuations, and in individual years the indicator may fall below the forecast line. The forecast represents the average trajectory, not the exact value for each year.

The way the three trajectories fan out on the graph is also noteworthy. In 2026, the difference between the scenarios is only 2.7 points, whereas by 2030 it widens to 16.0 points. This shows that forecast uncertainty increases over time and indicates that the reliability of forecasting beyond five years declines.

To interpret the forecast results in absolute terms, they can be converted to the 2025 base. In 2025, agricultural output amounted to 21,623.8 billion soums at current prices. Under the inertial scenario, the real volume by 2030 will increase by 19.9 percent relative to this base, by 21.7 percent under the baseline scenario and by 30.7 percent under the innovative scenario. Values in nominal terms are not presented in this study, as they depend on the rate of inflation.

The demographic factor should also be taken into account when assessing the scenarios. The resident population of the Republic of Karakalpakstan amounted to 2,061,488 people as of 1 July 2026. If the population grows by about 1.5–2.0 percent per year, the 3.7 percent growth under the inertial scenario yields per capita growth of only 1.7–2.2 percent. Under the innovative scenario, this figure is 3.5–4.0 percent. Hence, a significant improvement in agricultural output per capita is achieved only under the innovative scenario.

It is also useful to assess the scenarios in an international context. Sustained real growth of 4–5 percent per year in agriculture is considered a high figure in world practice and is usually recorded during a period of technological transition. In developed countries, sectoral growth is around 1–2 percent, as they are already close to the technological frontier. In Karakalpakstan, by contrast, the technological reserve is considerable – which makes the innovative scenario an achievable option.

At the same time, starting from a low technological base also has a downside: the volume of investment required for each additional percentage point of growth increases. At the initial stage, cheap and simple solutions – crop rotation, variety replacement – yield a significant effect; at the next stage, a transition to capital-intensive technologies becomes necessary. This means that financing needs increase in the second half of the innovative scenario.

The second part of the forecast was carried out on the basis of trend extrapolation by product type (Table 2).

Table 2. Trend forecast for the main product types up to 2030

Product type	2025 (actual)	Annual trend	2030 (forecast)	2030/2025	R^2	Forecast reliability
Grain and leguminous grain, tonnes	393,256	+9,010	391,200	0.99	0.550	Low: direction only
Vegetables, tonnes	419,043	+19,058	497,800	1.19	0.807	Conditionally reliable
Potatoes, tonnes	113,008	+6,525	147,500	1.31	0.971	Reliable
Meat (live weight), tonnes	130,313	+4,154	153,300	1.18	0.988	Reliable
Milk, tonnes	470,745	+14,823	552,200	1.17	0.992	Reliable
Eggs, thousand units	425,011	+21,981	553,800	1.30	0.962	Reliable

The table analysis first shows that the forecasts differ in their degree of reliability. For milk, meat, potatoes and eggs, the coefficient of determination exceeds 0.96 – i.e. the dynamics of these products are almost linear and the forecast is considered reliable. For vegetables, R^2 amounts to 0.807, and the forecast is assessed as conditionally reliable.

The situation for grain crops is qualitatively different. The R^2 value is only 0.550, which indicates that the dynamics of this indicator are highly volatile. The reason was identified in the studies mentioned above: the composition of the grain group is changing sharply – rice production has decreased 2.7-fold, while leguminous grain crops have increased 28.6-fold. Under such structural redistribution, constructing a linear trend for the aggregate indicator becomes methodologically unjustified.

For this reason, the grain forecast of 391,200 tonnes for 2030 should be interpreted not as a quantitative estimate but only as an indicator of direction. Its practical meaning is as follows: if current structural changes continue, the total volume of the grain group will remain at the 2025 level, i.e. growth will occur through redistribution within the group.

The highest growth rates are forecast for potatoes (1.31 times) and eggs (1.30 times). What the two products have in common is that they are types whose production can be organised on an industrial basis. The high dynamics for eggs are explained by the emergence of specialised poultry enterprises, while potatoes have relatively low water requirements and high market demand.

The situation for vegetables requires a separate comment. A sharp jump was recorded in this group in 2024 – the volume increased from 333,359 tonnes to 451,313 tonnes and then fell to 419,043 tonnes in 2025. Such a fluctuation reduces the accuracy of the trend equation and explains why R^2 is at the level of 0.807. Additional verification is required to establish the cause of the 2024 jump: it may be either a genuine increase in harvest or a change in accounting methodology.

The forecast rate for livestock products – meat and milk – is moderate (1.17–1.18 times). These indicators have high R^2 values, i.e. they rest on a stable trend. However, this stability has both a positive and a negative side: on the one hand, the forecast is reliable; on the other hand, the sector is effectively developing in an unchanged inertial mode, even though it accounts for 50.7 percent of gross output.

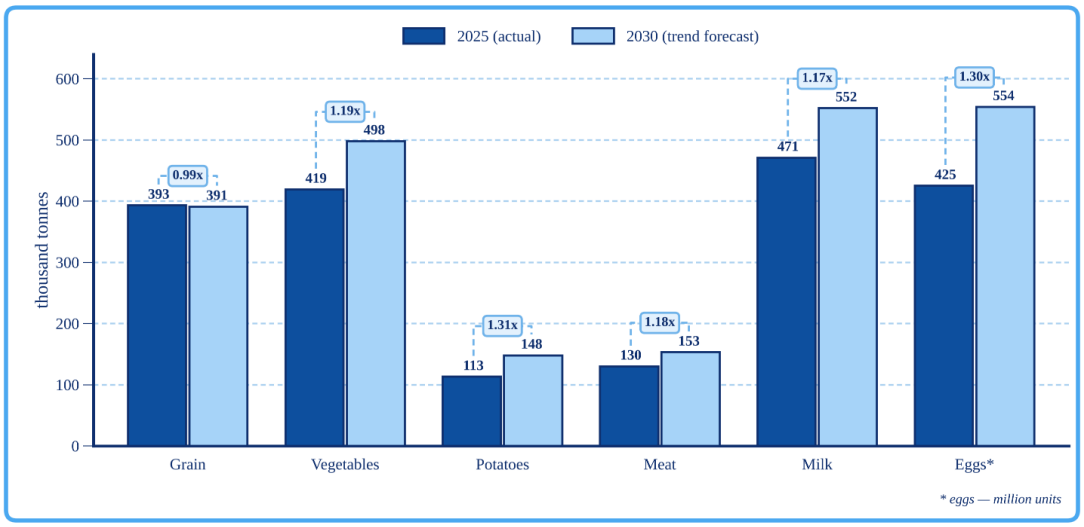


Figure 2. Actual 2025 and forecast 2030 volumes for the main product types

The chart analysis visually illustrates the difference in growth rates between product types. The coefficients above the bars range from 0.99 to 1.31 – i.e. the difference between the fastest- and slowest-growing products is more than threefold. Such a gap implies a significant change in the product structure by 2030.

It is particularly striking that the grain bars on the chart are almost equal in height. This reflects not the stagnation of the indicator but the balancing of opposing processes within its internal composition: the decline in rice production is being offset by the growth of leguminous grains and maize. If this offsetting continues over the forecast period, the total volume will be maintained; if rice production declines further, the volume may fall.

This situation shows the limitation of working with aggregate groups in forecasting. To obtain a reliable forecast for the grain group, it is necessary to break it down into its components, construct a separate trend for each of them and then aggregate the results. This is set as a methodological task for further research.

The practical conclusion drawn from the chart concerns the planning of processing capacities. The largest absolute growth is expected for milk and eggs (81.5 thousand tonnes and 128.8 million units, respectively). Appropriate infrastructure for processing and marketing these volumes must be established in advance; otherwise, growth will lead to lower product prices and reduced producer incomes.

A sensitivity analysis was carried out to test the reliability of the forecast (Table 3). It assesses how changes in the main factors affect the forecast result.

Table 3. Sensitivity of the forecast result to the main factors

Factor	Change scenario	Impact on the 2030 result	Likelihood
Water supply	The number of drought years doubles	The annual rate decreases by 0.8–1.2 percentage points	Medium
Sown area	Shrinkage continues at the current rate	Growth in crop farming stops	High
Water-saving technologies	Coverage is brought up to 30 percent	The annual rate increases by 0.7–1.0 percentage points	Medium
Cooperation in livestock farming	The commercialisation rate increases by 15 percent	The annual rate increases by 0.5–0.8 percentage points	Medium

Factor	Change scenario	Impact on the 2030 result	Likelihood
Processing capacities	Remain undeveloped	Price decline for milk and eggs; growth slows down	Medium

The sensitivity analysis makes it possible to identify the weakest point of the forecast. The only factor assessed as highly likely is the continued shrinkage of the sown area. This trend has been observed continuously since 2022, and stopping it requires accelerating the pace of land reclamation. If no action is taken, growth in crop farming may stop, which would shift all scenarios downwards.

Two factors acting in the positive direction – the expansion of water-saving technology coverage and the development of cooperation in livestock farming – may together raise the annual rate by 1.2–1.8 percentage points. This range is almost equal to the 1.8 percentage points required to move from the inertial to the innovative scenario. This confirms that the innovative scenario has a real basis: it rests not on abstract optimism but on work in two specific directions.

The processing capacity factor operates through a mechanism different from the others. It changes not the volume of production but its economic outcome: if capacities are insufficient, volume grows but prices fall and producers' incomes shrink. At the next stage, this removes the incentive to expand production and slows growth. For this reason, developing processing infrastructure is a necessary condition for achieving the forecast indicators.

The overall conclusion of the sensitivity analysis is that the uncertainty range of the forecast amounts to approximately 2.0 percentage points in terms of the annual rate – from 2.5 to 5.5 percent. The width of this range shows that the impact of management decisions in the region is high: the outcome is not predetermined and depends significantly on the measures adopted.

The conditions and risks of implementing the scenarios are summarised in Table 4.

Table 4. Conditions, risks and expected results of implementing the scenarios

Scenario	Condition for implementation	Main risk	Assessment from the standpoint of sustainability
Inertial (3.7 %)	Current policy and technological level are maintained; the water supply regime does not change	Shrinkage of the sown area continues; regional differentiation deepens	Unsatisfactory: high likelihood of growth at the expense of resource base depletion
Baseline (4.0 %)	Current programmes are fully implemented; the pace of land reclamation is maintained	Institutional rigidity in livestock farming persists	Average: volume grows, structural problems remain unresolved
Innovative (5.5 %)	Water-saving technologies are widely introduced; cooperation develops; the feedback system is launched	Large volume of initial investment; the implementation period may be extended	High: growth is ensured through resource efficiency

The table analysis takes the issue of choosing among scenarios to a new level. If the assessment is based solely on the growth rate, the difference between the inertial and baseline scenarios appears insignificant. When the sustainability criterion is added, however, they differ qualitatively: under the inertial scenario growth is likely to be

achieved at the expense of depleting the resource base, whereas under the innovative scenario it is achieved through resource efficiency.

Analysis of the risk column reveals an important asymmetry. The risks of the inertial and baseline scenarios are systemic in nature and intensify over time – shrinkage of the sown area and institutional rigidity will not resolve themselves. The risk of the innovative scenario, by contrast, relates to implementation: the volume of investment and the timeframe. This risk belongs to the manageable category, since it can be reduced through phased implementation and the attraction of external financing.

Analysis of the sustainability assessment column reveals another important aspect. The inertial scenario is characterised not only by a low growth rate but also by the likelihood of resource base depletion. In other words, it is not the safest option: doing nothing also carries its own risk, and this risk increases over time.

This conclusion is of great importance in substantiating policy decisions. Usually, the risk of introducing new measures is compared with maintaining the status quo, and the latter is taken to be the safe option. This analysis shows that in the conditions of Karakalpakstan such a comparison is incorrect: maintaining the status quo means continued shrinkage of the resource base.

On this basis, the following conclusion is drawn: the most likely scenario is the inertial one, while the most desirable is the innovative one. Narrowing the distance between them is the main task of agrarian policy. In quantitative terms, this task is as follows: to raise the average annual real growth rate from 3.7 percent to 5.5 percent, i.e. by 1.8 percentage points.

The sources of these 1.8 percentage points can be specified. As shown in the studies mentioned above, livestock farming accounts for 50.7 percent of gross output, and 89.9 percent of it is produced by small dehkan farms; raising productivity in this segment through cooperation is the largest reserve. The second source is raising yields per hectare in crop farming through water-saving technologies. The third source is increasing value added through processing.

A final comment is needed on the practical application of the forecast results. The scenarios can serve as a basis for setting the target indicators of regional programmes, but setting gross volume alone as a target indicator is insufficient. At least three indicators – the real growth rate, water intensity and the commercialisation rate in livestock farming – should be set together. Otherwise, the volume indicator may be met at the expense of the resource base.

A procedure for updating the forecast should also be established. It is recommended that long-term forecasts be recalculated at least once every two years and that scenario parameters be refined on the basis of new statistical data. This is particularly relevant for this region, where year-to-year fluctuations are high and a single anomalous year can significantly alter trend estimates.

4. Conclusion

First, three scenarios based on the real growth index have been calculated. By 2030, the real volume will increase relative to 2025 by a factor of 1.199 under the inertial scenario, 1.217 under the baseline scenario and 1.307 under the innovative scenario. The difference between the inertial and baseline scenarios is insignificant; a qualitatively different result is achieved only under the innovative scenario.Second, the average annual growth rate shows a declining trend over time: 4.01 percent for the ten-year period, 3.80 percent for the five-year period and 3.70 percent for the three-year period. This confirms that the sources of extensive growth are being exhausted and makes the inertial scenario the most likely option.Third, the trend forecast by product type showed the highest growth for potatoes (1.31 times) and eggs (1.30 times). The forecast for the grain group has low reliability (R^2 = 0.550), since a sharp structural redistribution is taking place within the group.Fourth, the expected absolute increases in milk and egg production (81.5 thousand tonnes and 128.8

million units) require advance planning of processing capacities; otherwise, growth may lead to lower prices and reduced producer incomes.Fifth, the quantitative task of agrarian policy is to raise the average annual real growth rate from 3.7 percent to 5.5 percent, i.e. by 1.8 percentage points. Its main sources have been identified as raising productivity in livestock farming through cooperation, increasing yields per hectare through water-saving technologies and increasing value added through processing.Sixth, the sensitivity analysis showed that the uncertainty range of the forecast amounts to approximately 2.0 percentage points in terms of the annual rate. The negative factor with the highest likelihood is the continued shrinkage of the sown area; two factors in the positive direction – water-saving technologies and cooperation in livestock farming – may together provide the additional growth needed to move to the innovative scenario.Seventh, forecast indicators should be monitored together with resource indicators, since a high growth rate is not in itself an indicator of sustainability. It is recommended that water intensity and the share of saline land be included in the monitoring system as mandatory elements.

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