



*III international scientific conference
Lisbon. Portugal
23-24.09.2025*

EXPLORING THE UNKNOWN: SCIENCE, IMAGINATION, DISCOVERY

Proceedings of the III International Scientific and Practical Conference

23-24 September 2025

LISBON. PORTUGAL

2025

UDC 001.1

BBC 1

III International Scientific and Practical Conference «Exploring the unknown: science, imagination, discovery», September 23-24, 2025, Lisbon. Portugal. 33 p.

ISBN 978-91-65424-39-5

DOI <https://doi.org/10.5281/zenodo.17459126>

Publisher: «SC. Scientific conferences»

Main organization: 

Editor: Hans Muller

Layout: Ellen Schwimmer

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The sample of the citation for publication is Gugin Aleksandr, Lisnievska Yuliia ANTI-ADVERTISING IN THE HOTEL BUSINESS // III International Scientific and Practical Conference «Exploring the unknown: science, imagination, discovery», September 23-24ss, 2025, Lisbon. Portugal. Pp.9-11, URL: <https://sconferences.com>

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INCREASING EXPORT POTENTIAL AND INTEGRATION INTO INTERNATIONAL MARKETS AS A DIRECTION FOR ENHANCING THE COMPETITIVENESS OF FOOD PRODUCERS IN AZERBAIJAN

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Abstract

The article examines the enhancement of export potential in Azerbaijan's food industry, its integration into international markets, and the impact of these processes on competitiveness. Based on statistical data, the dynamics of exports, the share of product groups, and the performance indicators of major producers are analyzed, while key challenges and future prospects are identified. The findings reveal that strengthening competitiveness is closely linked to innovation, government support, diversification of export markets, and institutional reforms.

Keywords: food industry, export potential, international markets, food producers, competitiveness, innovation, government support.

Introduction

In the context of global economic integration and the expansion of international trade relations, enhancing the competitiveness of Azerbaijan's food industry holds strategic importance. Strengthening export potential not only stimulates economic growth but also contributes significantly to food security, the development of the non-oil sector, and the increase of foreign currency revenues. In this regard, modernization of production in the food industry, alignment of products with international quality standards, and consolidation of positions in foreign markets are considered among the primary objectives.

Theoretical Background

Competitiveness is a multifaceted concept in economic theory and has been analyzed from various perspectives by different scholars. M. Porter (1990) [6] emphasizes the role of innovation and market conditions in shaping competitive advantages. Krugman (1994) [5], on the other hand, links the competitiveness of national economies primarily to productivity. Local economists [4;3] highlight factors such as modernization of production technologies, state support, and expansion of export opportunities as the main determinants in shaping a competitive environment in the food industry.

Current Situation of the Food Industry in Azerbaijan

According to data from the State Statistical Committee of Azerbaijan [1] and the International Trade Centre (ITC) [8], in recent years the country's food exports have demonstrated dynamic growth. The changes in export volumes and the distribution of product groups during the period 2015–2023 are reflected in the following tables and graphs.

Table 1.

Azerbaijan's food exports in 2015–2023 (million US dollars).

Year	Export (million US dollars)
2015	420
2016	460
2017	500
2018	530
2019	580
2020	620
2021	670
2022	710
2023	760

Source: Azerbaijan State Statistical Committee ,ITC Trade Map.

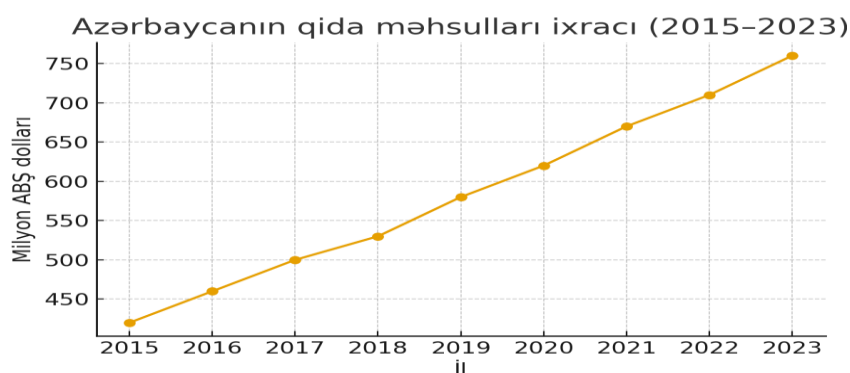


Figure 1. Dynamics of Azerbaijan's food exports by year.

Source: Azerbaijan State Statistical Committee, ITC Trade Map

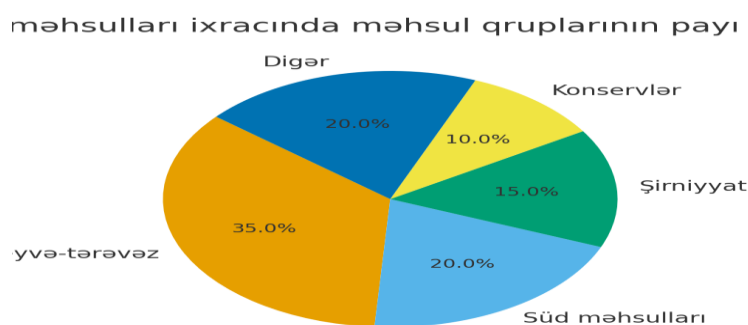


Figure 2. Share of product groups in Azerbaijan's food exports (2023).

Source: Azerbaijan State Statistical Committee, ITC Trade Map.

Factors Affecting Competitiveness

The main factors influencing the formation of competitiveness in Azerbaijan's food industry are as follows:

- Modernization of production and technological innovations;
- Compliance with quality standards and certification;
- Diversification of export markets;
- Government support and incentives;
- Development of human capital and management skills.

Each of these factors contributes to strengthening the competitive advantages of enterprises in the food industry, expanding access to international markets, and increasing export potential.

Comparative Analysis

A comparative analysis of Azerbaijan's leading food producers – Azersun, Milk-Pro, Atena, and Agrovita – reveals differences in their production capacities, export shares, and financial stability.

Table 2

Comparative indicators of major food producers.

Enterprise	Production capacity (thousand tons)	Export share (%)	Financial stability (1-5)
Azersun	850	45	5
Milk-Pro	320	18	4
Atena	400	22	4
Agrovita	270	15	3

Source: Azerbaijan State Statistical Committee, annual reports of enterprises.

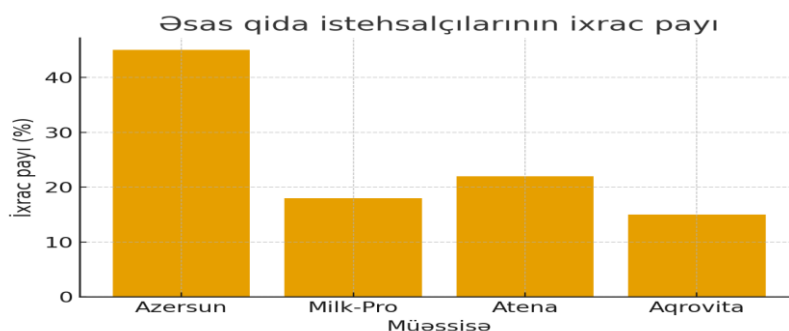


Figure 3. Comparison of export shares of major food producers.

Source: Azerbaijan State Statistical Committee, annual reports of enterprises.

Problems and Challenges

Despite certain achievements in enhancing competitiveness, Azerbaijan's food industry faces a number of problems and challenges. Primarily, in the process of expanding positions in export markets, non-tariff barriers, high logistics costs, and the degree of compliance with international standards pose significant obstacles. In addition, domestic producers often allocate insufficient resources to innovation, face limited R&D capabilities, and experience slow digital transformation, all of which hinder the acquisition of competitive advantages. At the same time, the low participation of small and medium-sized enterprises (SMEs) in exports prevents the full realization of the country's export potential.

Recommendations

Based on the conducted analysis, the following recommendations can be proposed to strengthen the international competitiveness of Azerbaijan's food industry:

1. Expand quality certification mechanisms and encourage the implementation of international standards;
2. Develop export logistics infrastructure and reduce transportation costs;
3. Support R&D centers and innovation-oriented production initiatives;
4. Broaden the adoption of digitalization technologies (ERP, artificial intelligence, big data);
5. Promote the participation of SMEs in export activities.

Conclusion

The study demonstrates that increasing export potential and integration into international markets is a decisive factor in enhancing the competitiveness of Azerbaijan's food industry enterprises. Analytical findings indicate that export performance and the implementation of quality standards are key determinants of competitiveness. Moreover, investments aimed at innovation and digitalization play a crucial role in ensuring long-term sustainability. For strategic development in the food industry, alongside government support, market-oriented approaches by enterprises themselves are essential. Thus, strengthening an export-oriented production strategy and ensuring compliance with international standards should be regarded as primary objectives for the future development of Azerbaijan's food industry [6, s. 112; 4, s. 45; 7; 8; 2, s. 52; 9, s. 33].

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Economic sciences

THE IMPACT OF NEUROMARKETING ON CONSUMER BEHAVIOR

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Abstract

This paper examines the role of neuromarketing in shaping consumer behavior, highlighting its theoretical foundations, methodological approaches, and practical applications in modern markets. Neuromarketing integrates neuroscience, psychology, and marketing science to better understand unconscious decision-making processes that drive consumer choices. The study demonstrates that neuromarketing techniques enhance the accuracy of consumer research, improve marketing communication strategies, and influence purchasing behavior by revealing implicit emotional and cognitive responses.

Keywords: *neuromarketing, consumer behavior, decision-making, neuroscience, behavioral economics.*

The study of consumer behavior has traditionally relied on models grounded in psychology, sociology, and economics, emphasizing rationality, utility maximization, and observable market preferences. However, contemporary research increasingly demonstrates that a significant proportion of consumer choices are not the product of rational calculation but are instead shaped by subconscious processes, emotions, and neurocognitive responses that escape conscious awareness. Neuromarketing has emerged as a multidisciplinary field at the intersection of neuroscience, cognitive psychology, and marketing science, with the explicit aim of uncovering these hidden drivers of consumer decision-making.

This approach is particularly relevant in the context of modern markets, where consumers are continuously exposed to a vast and highly competitive flow of information. Traditional surveys, focus groups, and self-reporting methods often fail to capture the implicit biases and automatic reactions that underlie actual purchasing behavior. Neuromarketing methods such as electroencephalography (EEG), functional magnetic resonance imaging (fMRI), eye-tracking, and galvanic skin response analysis provide objective measures of attention, engagement, and emotional arousal, allowing for a more accurate prediction of consumer actions.

Recent empirical studies highlight the strategic value of neuromarketing applications for business. According to the Nielsen Consumer Neuroscience report, advertising campaigns informed by neuromarketing insights show up to a 23% higher return on investment compared to those based on conventional consumer research [1]. Similarly, a Deloitte global survey indicates that companies integrating neurocognitive data into their marketing strategies outperform competitors in brand recall and customer loyalty indices by 15–20% [2]. These findings suggest that neuromarketing is not merely a supplementary tool but a transformative paradigm in understanding and influencing consumer behavior.

Furthermore, neuromarketing contributes to the development of new theoretical perspectives within behavioral economics and neuroeconomics. It expands the scope of consumer research by linking physiological responses, such as neural activation in reward-related brain regions, with observed market behavior. For instance, activation of the nucleus accumbens, a neural correlate of reward anticipation, has been shown to reliably predict purchase decisions, providing a neurobiological explanation for phenomena such as impulse buying and brand attachment [3].

In the global context, the diffusion of neuromarketing practices illustrates both opportunities and challenges. While developed economies have established robust infrastructures for the application of neuroscience-based consumer research, developing countries are increasingly adopting neuromarketing in digital commerce, mobile marketing, and social media campaigns. This reflects a broader trend of integrating artificial intelligence, big data analytics, and machine learning with neurocognitive tools to optimize consumer engagement and market outcomes. At the same time, ethical debates concerning consumer autonomy, data privacy, and potential manipulation have become central to the academic and policy discourse surrounding neuromarketing.

Scholars such as Ariely and Berns emphasize that traditional consumer research methods fail to capture unconscious motives, leading to inaccuracies in predicting real purchasing behavior [2]. Research in behavioral economics and neuroscience highlights that brain regions such as the prefrontal cortex and limbic system play critical roles in valuation, emotional processing, and decision-making [3].

Neuromarketing studies demonstrate that consumers' physiological responses to advertisements (e.g., changes in brain activation patterns or pupil dilation) often predict purchasing intentions more reliably than conventional market surveys [4]. For instance, fMRI-based studies reveal that strong activation in the nucleus accumbens correlates with a higher probability of product purchase [5].

Moreover, comparative studies show that neuromarketing can reduce the discrepancy between stated preferences and actual consumer behavior by 25–30%, thus increasing the reliability of marketing strategies [6].

Table 1.

Neuromarketing techniques and their application in consumer research

Technique	Application Area	Impact on Consumer Behavior
EEG	Measures brainwave activity	Identifies levels of attention and engagement
fMRI	Monitors brain activation patterns	Reveals emotional responses to advertising
Eye-tracking	Tracks visual attention	Optimizes ad design and product placement
Galvanic skin response	Measures arousal	Detects intensity of emotional involvement

Source: Developed by the author

The results suggest that neuromarketing offers significant advantages for analyzing and influencing consumer behavior. By uncovering unconscious cognitive and emotional processes, it enables marketers to design more persuasive campaigns and build deeper brand-consumer relationships. However, its application also raises ethical challenges regarding consumer autonomy, manipulation risks, and data privacy. For developing economies, adopting neuromarketing may enhance competitiveness but requires careful regulatory frameworks.

Neuromarketing represents a transformative approach to understanding consumer behavior. Its integration into corporate strategies enhances predictive accuracy, fosters stronger emotional connections with consumers, and improves overall marketing effectiveness. Nevertheless, the balance between innovation and ethical responsibility remains crucial. For future research, the expansion of neuromarketing into digital environments, artificial intelligence-driven analysis, and cross-cultural studies promises to further deepen its impact on global consumer markets.

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Geographical sciences

THE GEOGRAPHICAL ANALYSIS OF THE RECREATIONAL POTENTIAL OF WATER RESERVOIRS IN THE NAKHCHIVAN AUTONOMOUS REPUBLIC

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Abstract

In recent years, comprehensive measures have been implemented at the state level to foster the development of the non-oil sector in the Nakhchivan Autonomous Republic, with a series of normative-legal acts adopted to this end. Among the key areas within the non-oil sector, the development of tourism has been designated as a strategic priority. Although certain advancements have been made in this domain, the region continues to possess substantial untapped potential for the holistic development of all components of the tourism industry. Research indicates that natural landmarks, in particular, hold significant appeal for tourists. In this regard, the scientific evaluation of the tourism and recreational potential of existing water reservoirs in the Nakhchivan Autonomous Republic represents a highly relevant research direction, especially in the context of the region's socio-economic development.

Keywords: water reservoirs, tourism potential, recreational potential, geographical analysis, socio-economic development, sustainable tourism

Introduction: *The Nakhchivan Autonomous Republic is one of the regions endowed with rich hydrological potential. The various hydrological features present in the area—including mineral waters, waterfalls, lakes, marshes, and other water sources—are distinguished by their unique natural and geographical characteristics and hold significant importance from a tourism perspective.*

Studies on the tourism and recreational opportunities of hydrological features indicate that they provide favourable conditions for the development of both ecotourism and leisure tourism. Mineral waters occupy a special place in health tourism and the operation of balneological centres, while waterfalls and mountain rivers are particularly attractive locations for ecotourism and adventure tourism. Lakes and marshes, with their biological diversity and ecosystem services, also draw attention within the ecotourism sector.

Moreover, the close relationship between hydrological features and relief factors enhances their aesthetic value for tourism. Waterfalls cascading down mountain slopes, lakes surrounded by diverse relief forms, and mineral springs captivate tourists both visually and through their recreational potential.

Overall, the hydrological features of the Nakhchivan Autonomous Republic play a vital role in diversifying tourism and provide a scientific basis for a broader assessment of the region's tourism potential. Their evaluation using modern methods and effective management can contribute in the future both to environmental protection and to the socio-economic development of the population.

A significant portion of the hydrological features in the Nakhchivan Autonomous Republic consists of reservoirs created for various purposes. The Arpachay, Araz, Uzunoba, Nehram, Sirab, Khal-khal, and other reservoirs are not only important from an economic and socio-economic standpoint but also distinguished by their tourism and recreational potential. These reservoirs fulfil the region's water management needs while simultaneously providing extensive opportunities for organising tourism activities.

The location characteristics of the reservoirs and their interaction with the surrounding environment enhance their suitability for different forms of tourism. For example, the Arpachay reservoir offers favourable conditions for both ecotourism and fishing tourism, whereas the Uzunoba and Nehram reservoirs are promising for leisure tourism and the development of beach zones. Additionally, small-scale reservoirs located in foothill areas may serve as attractive sites for adventure tourism and sporting activities.

The recreational use of reservoirs is not limited to the development of the tourism sector alone but also contributes to the effective organisation of the population's leisure time, promotion of a healthy

lifestyle, and the preservation of the region's ecological environment. In this regard, the scientific study of the recreational potential of existing reservoirs in the Nakhchivan Autonomous Republic holds significant importance for the formulation of tourism strategies and the sustainable development of the region.

Reservoirs are classified into two main groups based on their hydrological characteristics and location principles:

- 1. Reservoirs constructed within riverbeds,*
- 2. Reservoirs located outside the river channels.*

Reservoirs belonging to the first group are large in volume and are directly formed and fed by river flows. Examples of such reservoirs in the territory of the Nakhchivan Autonomous Republic include the Araz reservoir constructed on the Araz River, the Arpachay (Davaolan) reservoir located on the Arpachay River, and the Vaykhir reservoir created on the Nakhchivanchay River.

Reservoirs in the second group are situated outside the river channels and are fed through special canals or channels branching off from rivers. Examples of this type of reservoir include Bananiyar Lake, fed by the Altinchay River, as well as Nehram Lake, Sirab, Uzunoba, Mazra, Gahab, Dize, Qanligol, Batabat Lakes fed by the Nakhchivanchay River, Salvarti Lakes, Nursu Lakes, and reservoirs such as Payiz Lake, Jahri-1, and Jahri-2 fed by the Jahrichay River, small-volume lakes formed in the Duylynychay River, and reservoirs constructed on some rivers of the Ordubad district.

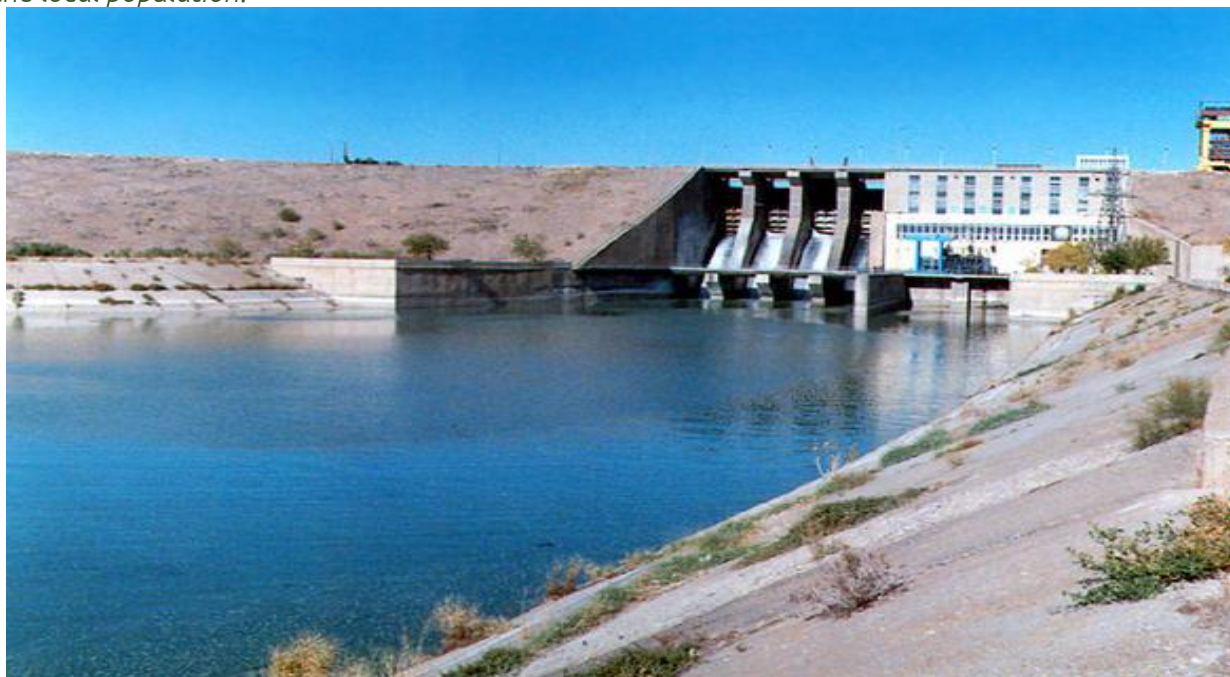
Thus, the Nakhchivan Autonomous Republic possesses various types of reservoirs constructed both within riverbeds and outside river channels, each playing a significant role in both water management and tourism-recreational activities. [Qurbanov & Bababəyli, 2015]

Araz Water Complex:

The Araz reservoir is located on the Araz River, at the border between the Republic of Azerbaijan and the Islamic Republic of Iran, at an elevation of 774.5 metres above sea level. The surface area of the reservoir is approximately 145.5 km² and exhibits seasonal fluctuations. When full, the water volume reaches 1.827 km³, with a catchment area of 54,155 km². The reservoir stretches 52 km in length and has a maximum width of 15 km. The annual fluctuation in water level ranges between 7.65 and 122.75 metres. Continuous hydrometric observations have been conducted since December 1971.

The Araz reservoir is a multifunctional economic facility. Its primary purposes are electricity generation and irrigation of agricultural lands. Four generators, each with a capacity of 10 megawatts, are installed at the dam, supplying electricity to both the Islamic Republic of Iran and the Nakhchivan Autonomous Republic. The reservoir also plays a vital role in irrigating the lands along the Araz River. Through an irrigation system that includes pontoon pump stations and the Garachukh canal, approximately 7,304 hectares of agricultural land are supplied with water. As water is delivered via pipelines, losses are minimised. [Babayev, N. S. (2004)]

Additionally, the Araz reservoir is important for fisheries and aquaculture. Various species of crustaceans and fish are cultivated here, with an annual production of around 100 tonnes, meeting the needs of the local population.



Beyond its roles in hydroelectric power and irrigation, the Araz reservoir holds significant potential for tourism and recreation. Its extensive surface area (approximately 145.5 km²) and length (52 km) contribute to its high scenic appeal. This creates favourable conditions for establishing recreational zones along the lakeshore and developing ecotourism routes.

The terrain and natural landscape features surrounding the reservoir, including mountain ranges and plains along the lakeshore, provide favourable conditions for organising activities such as photography, hiking, and birdwatching for tourists. Additionally, water sports such as canoeing and boating, as well as fishing tourism, can be developed on the lake. Through the local fishing enterprises operating in the area, tourists have the opportunity to engage in fishing and become acquainted with the local culture and economic activities.

The recreational infrastructure in the villages around the Araz reservoir, including small hotels and campgrounds, supports longer stays for tourists. This not only promotes the development of seasonal tourism in the region but also enhances employment opportunities for the local population.

Furthermore, the reservoir is attractive for ecotourism and scientific tourism. Its hydrobiological diversity, as well as the abundance of bird and fish species, offers extensive possibilities for scientific research and excursion tourism. Moreover, the purity of the water, the aesthetic value of the scenery, and the unique natural formations of the surrounding landscapes further enhance the tourism potential of the region.

Arpachay Reservoir

The Arpachay reservoir is located in the Dəvəölən region of the Nakhchivan Autonomous Republic, Azerbaijan, situated a few kilometres upstream from the Arpachay river's alluvial cone, on the canyon-like valley of the Daralayaz Mountains. The site of the reservoir lies at an elevation of 910 metres above sea level and holds strategic hydrological importance.

The reservoir was primarily constructed to provide irrigation for an area of approximately 30,000 hectares. It has a total capacity of 150 million cubic metres, with a useful water volume of 135 million cubic metres. The dam is 69 metres high, 480 metres long, and 10 metres wide at its crest. The central section of the dam consists of a reinforced concrete structure standing 81 metres tall.



The construction of the dam on the Arpachay has prevented sediment and suspended solids from entering the Araz River. This significant hydraulic engineering intervention has minimised the impact of flooding events, altered the hydrogeological conditions of the Arpachay delta, and caused substantial changes in the hydrological regime of the Araz River. [Qurbanov, Ə., Mustafayeva, N., & Bababəyli, N. (2013)]

The Arpachay reservoir plays an important role in increasing agricultural productivity, ensuring the sustainability of irrigation systems, and stabilising water supply in the region. It is also vital for maintaining groundwater levels, influencing the local microclimate, and preventing soil degradation.

Beyond its hydraulic and agricultural significance, the Arpachay reservoir possesses notable tourism and recreational potential. The western part of the reservoir is surrounded by mountain slopes that block sunlight during certain hours of the day, creating natural coolness in the area. This feature provides a comfortable resting environment for visitors during the summer months.

The surrounding areas have direct access via road, which facilitates the development of various activities around the reservoir, including ecotourism, mountain tourism, fishing, picnicking, and sightseeing tourism. The richness of the natural landscape and the mild climate make this area attractive for both local and international tourists.

Vaykhir Reservoir

Construction of the Vaykhir reservoir began in 1981. The reservoir basin is located at an elevation of 1,059 metres above sea level. The dam has a total height of 70.5 metres. Its main dam section, which is 69 metres high, is situated at an elevation of 1,128 metres above sea level. The dam is constructed from 1,104 metres up to 45 metres above sea level. The third phase of construction included a 24-metre-high earth dam. The dam is 550 metres long and 10 metres wide. Its upper section measures 230 metres in length and 468 metres in width. According to the project, the dam's volume is 5,508,013 cubic metres.

The construction of the Vaykhir reservoir has significant economic importance. Its development initiated the modernisation of the Nakhchivanchay irrigation systems, resulting in a reduction of water loss in agricultural enterprises. The process of supplying water from external reservoirs within the basin has been simplified. Previously, small reservoirs in high mountainous areas that supplied water to plains have diminished in importance, becoming primarily locally significant.

In the future, the reservoir holds potential for fishing, recreation, and tourism. Being relatively new, the ecological condition of the Vaykhir reservoir is comparatively stable. Nevertheless, despite its recent use, suspended solids and sediment accumulation at the reservoir's inlet are clearly visible during spring and autumn, periods when their volumes are typically low. A distinguishing feature of the Vaykhir reservoir is that it is fed solely by Nakhchivanchay waters, which do not originate from foreign countries, ensuring that no industrial enterprises affect the reservoir's ecological status.

The reservoir is highly suitable for water sports. Activities such as swimming, canoeing, and kayaking can be developed to attract tourists and support the organisation of tourism in the region. It is also possible to establish a wide-ranging tourism centre by incorporating balneological activities, such as sunbathing with therapeutic benefits. Moreover, tourist routes could be organised to nearby mineral water deposits at Badamli and Vaykhir, as well as various geological monuments. Therefore, the creation of a tourism centre encompassing the surrounding mid-mountain areas would be beneficial.

Sirab Reservoir

The Sirab reservoir was constructed in 1978 for irrigation purposes, located 2 km north of Zeynaddin village, between Sirab and Qahab villages. The reservoir's construction coincides with the Turyan canal, which directly connects Nakhchivanchay River to Sirab Lake. The primary purpose of building the concrete Turyan canal was to utilise the waters of the Nakhchivanchay River for irrigation and to fill the Sirab reservoir, which has a volume of approximately 12.8 million cubic metres.

The filling of the reservoir typically begins between late November and December, although this period may vary depending on climatic conditions. The main water accumulation months are February, March, and April, coinciding with snowmelt and periods of heavy rainfall. The inflow water is directed from Nakhchivanchay through the separation gates of the Vaykhir water intake facility, located in the central part of the river, into the Turyan canal, and subsequently into Sirab Lake. The reservoir primarily fills during winter and early spring when irrigation needs are insufficient or weak. During this time, snowmelt and heavy rains often cause floods in the mountainous areas of Nakhchivanchay; unlike dryland canals, this does not impede the flow of water into the Turyan canal.

However, the turbidity of the river water is currently very high, which has a severely negative impact on the ecological condition of both the lake and the canal. Natural factors affecting the ecological state of Sirab Lake mainly originate from the Nakhchivanchay basin. The construction of the Vaykhir reservoir, through the left-bank canal, has reduced the amount of suspended solids entering the lake. Since the water supplied to the canal comes directly from the Vaykhir reservoir, which acts as a filter, this prevents the accumulation of suspended solids in the Sirab reservoir and helps maintain its useful volume. Məmmədov, M. (2002).

The importance of Sirab Lake for tourism, recreation, and leisure was already recognised during the Soviet era. Health sanatoria were established around the reservoir; however, due to poor management and insufficient promotion, these facilities were later discontinued. Although Sirab mineral water is indispensable in treating gastrointestinal diseases, the mineral water source is located approximately one kilometre away from the reservoir. Taking these two natural features into account, it is possible to develop a large-scale balneological treatment and tourism-recreational complex in the area. Additionally, hunting tourism could also be developed. The waters of the reservoir, situated along the Vaykhir mountain range, can attract tourists, and the development of water sports is feasible.

Uzunoba Reservoir

The Uzunoba reservoir was established in 1961 with the purpose of creating a reserve water supply for irrigating the surrounding areas, fed by the waters of the Nakhchivanchay River. It is situated 2 km west of Uzunoba village, at an altitude of 1000 metres, on the right bank of the Nakhchivanchay River. The reservoir has a total capacity of 9.0 million cubic metres.

The reservoir provides favourable conditions for the development of fishing activities; however, this resource is utilised solely by the local population. The ecological condition of Uzunoba Lake is currently very critical. Primarily, the reservoir is almost filled to capacity, and in some cases, it is effectively at dead storage level. When the lake is emptied, the water channels through which the reservoir drains become visible. Approximately 70% of the concrete coating of the spillway has deteriorated, which poses a significant risk for the city of Nakhchivan in the future. Several seepages have already been observed as warning signs. The reservoir is so full that it is essentially considered empty in terms of water usability, making fishing activities unfeasible.

Public catering facilities, beaches, and other tourism zones have been established in the area for the recreation of the local population. Additionally, the climatic and recreational factors of the region offer further potential for tourism development.

Bənəniyar Reservoir

The Bənəniyar reservoir was constructed in 1987 west of Bənəniyar village, on the right bank of the Altıncaçay River, primarily for irrigation purposes. This reservoir, comprised of a dam structure, has a total capacity of 17.4 million cubic metres, with a useful volume of 15.7 million cubic metres. It is utilised to irrigate approximately 0.8 thousand hectares of land. Water is supplied to the reservoir via a concrete canal from the Əlincəçay River. The natural factors of the area are influenced by the Əlincəçay River and its reservoir.

The basin has virtually no forest coverage, and the Ləkətağçay basin is characterised by sparse forest vegetation. This river belongs to the group of rivers exhibiting a spring regime. The main sources of the river's inflow are approximately 45% from snow and rainfall, and 55% from groundwater. In multiyear averages, 15% of the reservoir's filling is from underground sources, 71% from snowmelt, and 14% from rainfall; in dry years, the proportions shift to 25% groundwater and 17% rainfall. Therefore, the reservoir's full capacity is typically reached during rainy seasons, when it is actively utilised. The flow velocity of the Əlincəçay is estimated at 1.25 cubic metres per second, with the highest recorded discharge of 47.1 cubic metres per second in July 1960.

Average water consumption in the Əlincəçay is 0.12 kg/s, with a flow rate of 4,100 tonnes. The average annual turbidity is 170 g/m³, peaking at 9,100 g/m³ in July 1960. The turbidity of the river decreases when the Bənəniyar reservoir fills, which contributes to the gradual reduction of the reservoir's storage capacity over time.

The average water temperature in the basin is 0.9 °C in January and 15.6 °C in August. Ice cover persists for approximately one and a half months, during which time the reservoir's filling becomes more difficult due to the obstruction of water flow by ice. The water of the river is classified as bicarbonate-calcium type and is suitable for irrigation.

Nehrəm Reservoir

The Nehrəm reservoir is located northwest of Güznüt village. Since 1965, it has been an integral part of the region's water management infrastructure. With a total capacity of 6 million cubic metres, this reservoir holds significant importance due to its distance from natural water sources. It is primarily fed by two water sources: the Əlincə River and the Naxçıvan River. Water is supplied from the Naxçıvan River via the Terran canal and the Halqa ditch, which separate it from the right bank of the Əlincə River near Bənəniyar village.

The reservoir's water supply period typically spans from December until mid-March, while its utilisation period extends from mid-April to late November. Thanks to this dam, an area of 1,193 hectares

is irrigated, encompassing the villages of Güznüt, Çeşməbasar, Qarğabazar, and Nehrəm. In recent times, the reservoir has been used exclusively for irrigation purposes.

The ecological condition of the reservoir is very poor. Despite being supplied with water from distant sources, it has become heavily silted with suspended solids. The reservoir basin has effectively transformed into a swamp. Currently, it is no longer possible to store reserve water in the reservoir. Although efforts have been made to remove silt from the reservoir bed, no comprehensive dredging or restorative works have been undertaken.

Salvardı Lakes

The Salvardı lakes can be categorised into three groups based on their geographical location. The first group comprises 12 lakes located to the northeast of the Salvardı Mountain (3,161.5 metres). The largest lake in this northeastern cluster is Zərdovgol. The second group consists of 17 lakes situated to the southwest and west, including notable lakes such as Pirigöl, Dumagöl, Dibiyoq, Təzəgol, and Şahbulaq. The third group, located to the north, includes 13 lakes known as the Batabat lakes, which have subsequently been expanded and converted into reservoirs. These lakes differ in their relative sizes.

Additionally, there are numerous lakes between the Cindağ mountain (2,674 m) and Ağbulaq village. Some of these lakes temporarily dry out by late summer, while others have been developed into small reservoirs, such as Salalı and Niyazlar. [Bababəyli, N. S., Qurbanov, Ə. K., & Məmmədova, Y. F.]

The Salvardı lake is surrounded on the east and south by peaks exceeding 2,800 metres in altitude. Numerous high-altitude springs flowing into the lake from the south support a stable water level throughout the year. During the warmer period, the water consumption in the lake varies from 75 to 20 litres per second. The lake contains bicarbonate water, with the total mineral content fluctuating throughout the year and reaching its peak of 90–98 mg/l in September.

Given the favourable conditions and economic importance of the lake, several dams have been constructed in the north-western part of the basin. However, these have experienced multiple breaches, with severe destructive floods occurring in 1956 and 2001.

Batabat Lakes

The Batabat lakes are located on the southwestern slope of the Bicənək Pass, in the upper part of the Naxçıvan River basin, at an altitude of 2,113 metres above sea level. In the southern part of Bicənək Pass, over time, there are approximately five marshy areas covered with peat, primarily fed by springs and snowmelt waters. Considering the favourable location of these marshes, some have been enlarged by constructing dams since 1946. Batabat Lake is the largest among these wetlands and is mainly fed by the Xorrbulaq stream flowing from the northeast, as well as partially by snow falling into the basin. The lake covers an area of 16 hectares, with a length of 530 metres, an average width of 302 metres, and a shoreline measuring 1,800 metres. The mineral content of the water in Xorrbulaq feeding the lake is 124 mg/l, and the water is classified as hydrocarbonate-calcium type.

The second lake in the Batabat group is located one kilometre southwest of the Upper Lake, at an altitude of 2,000 metres above sea level. The surface area of this lake is 12 hectares. It is fed by both water reserves and snow, as well as by water flowing from the Upper Lake.

The third lake lies to the southeast of the previous one, at an altitude of 1,900 metres. It measures 400 metres in length and 320 metres in width. This lake is fed by water flowing from the first and second upper lakes, along with several small streams entering from the northeast. [Bababəyli, N. S. (2010)]

The Batabat lakes and their surroundings present a picturesque and favourable environment for both flora and fauna, as well as for the hydrographic network, making the area well-suited for recreation. Until the 1980s, various state institutions capitalised on the area's natural beauty and comfort by establishing dormitories, pioneer camps, and children's entertainment centres. Around the Upper Lake, city residents, regardless of their backgrounds, pitched tents to stay and enjoy their summer holidays in nature.



To support visitor services, mobile service units from relevant ministries and agencies operated in the area, providing cultural activities such as film screenings and libraries, commercial services, and medical facilities. For public safety, police stations were also present. The Ministry of Culture organised touring performances in the region.

One of the key advantages of the Batabat lakes area is the availability of all necessary natural components for relaxation in close proximity. Another advantage is the convenient transportation infrastructure, which facilitates easy access to the site.

Blood lake

Blood lake is situated on the right tributary of the Naxçıvan River, 2.5 km southwest of Kiçikçay Peak (3,119.6 m), at an altitude of 2,424 meters above sea level. The lake covers an area of 10.2 hectares, with a maximum width of 222 meters, a length of 460 meters, a shoreline measuring 1,430 meters, and a curvature coefficient of 1.26. Originally, Blood lake was a small natural lake, historically used primarily to provide water for livestock grazing in the surrounding pastures. The lake's capacity is approximately 1.2 million cubic meters.

Historical sources indicate that the lake was first artificially enhanced by Heydər xan in the mid-16th century, and later in the late 19th century (from 1865) by Kəlbəlixan, who renovated the dam and increased the lake's volume.

The primary water sources feeding Blood lake are atmospheric precipitation and groundwater springs surfacing in the area. Water from the lake flows out through a dam located on the southern side and cascades down into the Küküçay River via a waterfall reaching up to 10 meters in height. Ice begins to form on the lake's surface in the first half of November, and the lake remains ice-covered until late April or early May.

During late spring and summer, the area around Blood lake boasts rich flora within its water basin. Numerous potable water springs in the vicinity make the lake a popular spot for recreational activities. To the northeast lies Samanlı Pınar, and to the southwest stands Küküdağ, the highest peak of the Dərələyəz mountain range; however, the spring water from Küküdağ does not flow into the lake. The lake is nourished by several beautiful springs, contributing to the scenic beauty of the area.

Blood lake and its surroundings offer excellent opportunities for developing water sports, winter tourism, mountaineering, and hiking tourism in the region.

Conclusion

Nakhchivan Autonomous Republic stands out as one of the geographically water-scarce regions, which necessitates the rational management and multifunctional use of its water resources. In recent years, the reservoirs constructed in the region have not only served irrigation and drinking water supply purposes but their socio-economic, ecological, and recreational potential must also be taken into consideration. The research has shown that many of the reservoirs in Nakhchivan AR possess significant opportunities for tourism and recreation.

The morphometric and morphological characteristics of the area, especially water bodies located in high and mid-mountain zones (such as Batabat, Blood lake, Salvardi, etc.), create favorable conditions for tourism due to the aesthetic environment, landscape diversity, and the presence of unique hydrographic and geological features. These lakes are also situated in advantageous geographical locations for the development of mountain tourism and winter sports. The presence of long-lasting snow cover in winter allows these areas to be considered as potential zones for skiing, snowboarding, and other winter activities.

The study also revealed that reservoirs located in the plains of Nakhchivan AR (such as Büyük Araz, Arpaçay, Vayxır, Yaycı, etc.) are suitable for water sports, fishing, birdwatching, and hunting activities. In these areas, multi-purpose tourism routes (including ecotourism, sports tourism, rural tourism, etc.) can be established to diversify tourism. Furthermore, these routes can contribute to the socio-economic development of surrounding villages and districts.

Considering all these factors, it can be stated that the tourism and recreational potential of the existing reservoirs in the Nakhchivan Autonomous Republic has not yet been fully realized. To address this, the following measures are recommended:

- Strengthening the infrastructure of reservoirs (transportation, communication, catering facilities, etc.);
- Planning and promoting tourism routes at local and regional levels;
- Organizing coordinated activities among the Ministries of Culture, Youth and Sports, Tourism, and Ecology;
- Involving local communities in these processes and adhering to principles of ecological sustainability.

In conclusion, the reservoirs in the Nakhchivan Autonomous Republic should be regarded not only as infrastructures fulfilling technical and agricultural needs but also as economically viable tourism sites with broad recreational opportunities. By implementing appropriate strategies to harness this potential, the tourism sector in the region can be developed, new jobs can be created, and sustainable income sources can be provided for local communities.

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Medical sciences

THE ROLE OF VITAMIN D IN THE PREVENTION AND TREATMENT OF VARIOUS DISEASES

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Abstract

The article examines the role of vitamin D as one of the most significant micronutrients affecting a wide range of physiological processes in the human body. Particular attention is paid to its participation in the regulation of calcium-phosphorus metabolism, maintenance of bone tissue, functioning of the immune, cardiovascular, endocrine and nervous systems. The causes of vitamin D deficiency are analyzed in detail, including insufficient sun exposure, unbalanced diet, obesity, chronic liver and kidney diseases, as well as gastrointestinal tract pathologies. The article presents current data on the consequences of hypovitaminosis for children and adults: the development of rickets, osteomalacia, osteoporosis, increased risk of infectious, autoimmune and psychoneurological diseases.

Particular attention is paid to the “non-classical” effects of vitamin D: its role in the prevention of cancer, type 1 and 2 diabetes, cardiovascular disease pathologies and cognitive impairment. Therapeutic approaches are considered, including the combined use of vitamin D with calcium and other drugs, as well as the prospects for personalized medicine that takes into account genetic factors. The importance of optimizing daily intake rates and monitoring levels is emphasized.

25(OH)D in the blood.

Thus, vitamin D appears not only as a “bone vitamin”, but also as a universal regulator of many body systems, playing a key role in the prevention and treatment of a wide range of diseases and opening up prospects for further interdisciplinary research.

Keywords: autoimmune diseases, immunity, osteoporosis, prevention, cardiovascular diseases

Introduction: Over the past decades, vitamin D has ceased to be perceived solely as the “sunshine vitamin” or the “bone vitamin.” Today, it is seen as a multifunctional regulator on which the health of a number of body systems depends. The level of vitamin D in the blood depends not only on the strength of bones, but also the state of the immune system, the cardiovascular system, psycho-emotional balance and even predisposition to oncological diseases. Interest in this nutrient has rapidly increased in the 21st century, when it became obvious that its deficiency is not local, but a global problem affecting millions of people around the world [10, p. 75].

Against the backdrop of urbanization, sedentary lifestyles and reduced time spent on sun Vitamin D deficiency has become a major public health challenge, especially during the pandemic COVID-19, when numerous studies confirmed the link between low vitamin D levels and severe disease. Vitamin D thus became the symbol of a new approach to disease prevention that combines fundamental biochemical mechanisms and strategic tasks of medicine of the future.

Vitamin D is one of the key micronutrients that ensures the normal functioning of the human body. It is involved in many physiological processes, including calcium-phosphorus metabolism, maintaining bone strength, regulating the functioning of the immune, cardiovascular and endocrine systems [1, [p. 267] Vitamin D deficiency is recognized as a global problem: according to the World Health Organization, more than 1 billion people worldwide suffer from it [10, p. 75].

Modern research shows that vitamin D plays an important role not only in the prevention of rickets and osteoporosis, but also in reducing the risk of infectious, autoimmune and oncological diseases [2, p. 1110]. This determines the high relevance of studying its role in the prevention and treatment of various pathologies.

Vitamin D is a fat-soluble vitamin-like hormone and exists in two main forms:

- **D₂** (ergocalciferol) - enters the body with plant products;

- **D₃ (cholecalciferol)** - is synthesized in the skin under the influence of ultraviolet radiation rays and is contained in products of animal origin [6, p. 1690].

The main source of vitamin D for humans is solar radiation. Under the influence of ultraviolet rays, provitamin D₃ is formed from 7-dehydrocholesterol in the skin, which is then converted into cholecalciferol. In the liver, hydroxylation to 25-hydroxyvitamin D, the main biomarker of vitamin D status in the body, and in the kidneys the active form is formed - 1,25-dihydroxyvitamin D (calcitriol) [4, p. 1035].

Dietary sources of vitamin D include fatty fish, eggs, and dairy products, but its content in food is relatively low, making cutaneous synthesis the main route of providing the body with this nutrient [5, p. 1808].

The main functions of vitamin D can be divided into several areas:

1. **Regulation of calcium-phosphorus metabolism**- promotes the absorption of calcium and phosphorus in the intestines, regulates bone mineralization.

2. **Maintenance of the skeletal system**- prevents the development of rickets in children and osteoporosis in adults.

3. **Endocrine regulation**- affects the function of the parathyroid glands, insulin secretion and glucose metabolism.

4. **Neuroprotection**- reduces the risk of depression and cognitive impairment.

5. **Cardioprotection**— improves the functioning of the cardiovascular system, reduces blood pressure and the severity of inflammatory processes [3, p. 977].

Thus, vitamin D plays a complex, multifactorial role that goes far beyond bone metabolism.

The main causes of vitamin D deficiency include:

- lack of sun exposure (urban lifestyle, use of sunscreen);
- low vitamin D levels in the diet;
- obesity, in which the vitamin is deposited in adipose tissue;
- chronic kidney and liver diseases that disrupt the process of formation of active metabolites;
- gastrointestinal tract pathologies (celiac disease, malabsorption syndrome) [7, p. 755].

In children, vitamin D deficiency leads to the development of rickets and stunted physical growth, and in adults, to osteomalacia and osteoporosis [4, p. 1038]. Deficiency of this nutrient is also associated with an increased risk of diabetes, depression, cardiovascular diseases and infectious pathologies [7, p. 753].

The preventive role of vitamin D is varied and covers different levels functioning of the body. First of all, it is necessary for the normal formation and maintenance of the skeletal system. In children, sufficient levels of vitamin prevent rickets, and in adults it reduces the risk of osteoporosis and fractures [5, p. 1810]. This is of particular importance in old age, when the efficiency of vitamin D synthesis in the skin decreases, and the likelihood of falls and injuries increases significantly. Additional provision of the body with vitamin D in this age group is considered a factor that reduces mortality and improves quality of life.

From the point of view of infectious pathology, vitamin D plays a fundamental role in the activation of innate immunity. It stimulates the work of macrophages and promotes the production of antimicrobial peptides - cathelicidins and defensins, which have antiviral and antibacterial action [8, p. 2504]. Large studies have shown that people with adequate levels of vitamin D have a reduced incidence of acute respiratory infections and tuberculosis. This was especially evident during the COVID-19 pandemic: patients with vitamin D deficiency had a more severe course of the disease, which attracted the attention of researchers to its immunomodulatory potential [9].

In addition to its effect on innate immunity, vitamin D is involved in modulating the adaptive immune response. It helps maintain a balance between pro-inflammatory and anti-inflammatory mechanisms, reducing the risk of autoimmune diseases.

It has been established that in regions with low insolation, multiple sclerosis is more frequently registered, and the risk of developing type 1 diabetes is also higher, which is associated with the influence of vitamin D on the function of T-lymphocytes and the secretion of insulin by the pancreas [3, p. 982].

Of particular interest is cancer prevention. A number of epidemiological studies have shown that maintaining optimal vitamin D levels is associated with a lower risk of malignancies, including colon, breast, and prostate cancer [2, p. 1112]. Proposed mechanisms include regulation cell cycle, induction of apoptosis and inhibition of angiogenesis in tumor tissues.

The therapeutic value of vitamin D goes far beyond the skeletal system. In complex therapy for osteoporosis, it is used together with calcium and bisphosphonates, helping to improve bone mineral

density and reduce the risk of fractures [1, p. 270]. In osteoarthritis, vitamin D is involved in maintaining cartilage tissue metabolism.

Cardiovascular diseases are also closely linked to vitamin D levels. It influences blood pressure regulation through the renin-angiotensin system and reduces inflammation of the vascular wall. Vitamin D deficiency is associated with an increased risk of atherosclerosis and coronary heart disease [6, p. 1692].

In endocrinology, vitamin D is considered a factor that increases tissue sensitivity to insulin. In patients with type 2 diabetes, its use improves glycemic control, especially when combined with dietary modification and regular physical activity [5, p. 1815]. Thus, vitamin D is an important element of the complex prevention of metabolic syndrome.

In psychiatry and neurology, there is accumulated data showing that patients with low levels Vitamin D is more likely to suffer from depression and cognitive impairment. In a number of clinical studies, adding the vitamin to therapy improved mood and reduced severity of depressive symptoms [3, p. 983]. Active research is underway into its role in the prevention of neurodegenerative diseases, including Alzheimer's disease. In addition, in infectious diseases, vitamin D is considered as adjunctive therapy. A meta-analysis has shown that regular intake of vitamin D reduces the risk of developing acute respiratory infections [9]. Although COVID-19 Vitamin D is not a medicine; maintaining its optimal level helps to make the disease milder and reduce the risk of complications.

Daily intake of vitamin D depends on age, physiological condition and body characteristics. According to the recommendations of the World Organization health and national clinical guidelines [10, p. 150], the optimal doses are:

- **children under 1 year**— 400–600 IU;
- **children over one year old and adults**— 600–800 IU;
- **elderly people and pregnant women**— up to 1000–2000 IU.

In countries with northern latitudes, the practice of mandatory fortification of food products (for example, milk and infant formula) with vitamin D is widely used. This strategy has proven effective in reducing the prevalence of its deficiency and is recognized as a significant public health measure [5, p. 1812].

However, it is important to consider the risk of overdose. Excessive consumption of vitamin D can lead to hypercalcemia, accompanied by nausea, heart rhythm disturbances, and kidney damage. In this regard, with long-term use of drugs, regular monitoring of the level of 25(OH)D in the blood is necessary [7, p. 756].

Modern research pays special attention to the so-called “non-classical” effects of vitamin D. In addition to participating in the regulation of calcium-phosphorus metabolism, it associated with the prevention of oncological, psychoneurological and metabolic diseases [2, p. 1115]. More and more data indicate its importance for reproductive health, as well as for reducing the risk of pregnancy complications.

Particular attention is paid to genetic aspects. Polymorphisms of the vitamin D receptor (VDR) gene can determine individual differences in its absorption and biological action [3, p. 985]. This opens the way to the development of personalized medicine, when prevention and therapy will be selected taking into account the genetic characteristics of the patient.

Thus, in the future, vitamin D can be considered not only as a preventive measure, but also as an element of targeted therapy for a wide range of diseases. Today, it acts as a universal regulator of many body systems, going far beyond the usual concept of a “bone vitamin” [1, p. 268].

Vitamin D deficiency remains a global problem associated with an increased risk of developing numerous pathologies. Providing the body with a sufficient amount of this nutrient is of fundamental importance for both the prevention and treatment of various diseases [5, p. 1809]. Prospects for further research include expanding the clinical use of vitamin D, developing personalized prevention regimens, and integrating it into public health programs at the international level [10, p. 150].

In recent years, attention to vitamin D as a health factor has increased significantly. Scientists have conducted a number of large studies to determine how it affects various body systems. One of the most significant is the VITAL Study, conducted in the United States. It involved more than 25,000 people who received vitamin D and omega-3 for several years. The main goal was to evaluate its effect on cardiovascular diseases and cancer. The results showed that in the general population, vitamin D did not change the risk of developing these pathologies, but in people with an initial deficiency, there was a noticeable decrease in severe cancer outcomes and overall mortality [2, p. 1113].

Another important study was the D2d Study, which focused on the prevention of type 2 diabetes. It assessed whether vitamin D could reduce the likelihood of prediabetes turning into diabetes. It was shown that participants with low levels of the vitamin had a significantly lower risk of disease

progression, which confirms its role in regulating carbohydrate metabolism and increasing tissue sensitivity to insulin [3, p. 982].

Significant data were also obtained as a result of a meta-analysis published in BMJ (2017), which showed that in people with vitamin D deficiency, regular supplementation reduces the risk of acute respiratory infections, including influenza and colds. The effect was especially pronounced in those who had previously received virtually no vitamin D [9].

These studies demonstrate that vitamin D cannot be considered a "miracle cure." However, maintaining adequate levels does improve health, especially in people with an initial deficiency [7, p. 754].

The physiological effect of vitamin D is explained by the presence of specific receptors (VDR), which are present in almost all tissues of the body. The active form of the vitamin binds to these receptors and regulates the expression of hundreds of genes involved in various processes. Thus, in bone tissue, vitamin D stimulates the synthesis of osteocalcin and regulates mineralization processes [6, p. 1693]. In the immune system, it activates macrophages and stimulates the production of antimicrobial peptides - cathelicidins and defensins, which increase the body's resistance to viral and bacterial infections [8, p. 2506].

In the endocrine system, vitamin D improves the functioning of the β -cells of the pancreas, supporting insulin secretion and glucose metabolism [3, p. 983]. In the cardiovascular system, it affects the renin-angiotensin system, helping to lower blood pressure and reduce inflammatory processes in the vascular wall [6, p. 1695].

Modern research shows that vitamin D should be considered not just as a vitamin, but as a steroid hormone with systemic action. This explains its multifaceted impact on health and opens up new prospects for its use in the prevention and treatment of a wide range of diseases [2, p. 1114].

Neurology and psychiatry. Vitamin D is actively involved in the regulation of neurotrophic factors, maintains neuronal health and reduces the level of neuroinflammation. Low serum vitamin D levels are associated with depression, anxiety disorders and cognitive decline [3, p. 982]. Clinical studies show that in older people, maintaining adequate vitamin D levels slows down age-related decline in memory and cognitive abilities, improves concentration and overall psychoemotional state [9].

Oncology. Vitamin D is considered as an auxiliary element in the prevention and therapy of malignant neoplasms, including breast, colon and prostate cancer. Its protective effect is associated with participation in the regulation of the cell cycle, activation of apoptosis, inhibition of angiogenesis and suppression of uncontrolled cell proliferation [2, p. 1114].

Genetics. Polymorphisms of the vitamin D receptor gene (VDR) explain individual differences in the absorption and metabolism of the vitamin. This opens up prospects for personalized medicine, when prevention and therapy of deficiency are selected taking into account the genetic characteristics of a particular patient [3, p. 985].

Combined approaches. A promising direction is the study of the combined use of vitamin D with omega-3 fatty acids, antioxidants, probiotics and minerals. Clinical data confirm that the complex effect has a more pronounced effect compared to the isolated intake of vitamin D [8, p. 2508].

These trends confirm that vitamin D is going beyond the "classical" understanding and is becoming the object of interdisciplinary research.

Reproductive health. Vitamin D deficiency has a negative impact on the reproductive system. In women, it can lead to menstrual irregularities, increase the risk of polycystic ovary syndrome, reduce fertility, and increase the likelihood of pregnancy complications, including preeclampsia, gestational diabetes, and premature birth [5, p. 1811]. Vitamin D is critical for the fetus: it is involved in the formation of the bone and nervous systems, as well as in the development of immunity. Deficiency in the mother is associated with low birth weight, a high risk of rickets, and delayed development. In men, vitamin D maintains normal testosterone levels, improves sperm quality, including their motility and viability, which ultimately contributes to successful conception [7, p. 755].

Prevention and public health. Vitamin D deficiency is a global problem, affecting even countries with sufficient sunlight. The elderly, children, pregnant women and socially vulnerable groups are particularly vulnerable. Prevention measures include:

fortification of food products (milk, yoghurts, margarine, vegetable oils). The experience of Finland and Canada demonstrates that such programs can significantly reduce the incidence of rickets and osteoporosis [4, p. 1037];

regular screening and monitoring of 25(OH)D levels in children, pregnant women and the elderly;

educational work aimed at informing the population about the importance of sunlight, healthy eating and the need for preventive supplements.

These measures not only reduce medical risks, but also decrease the number of hospitalizations, fractures and chronic complications, which ultimately reduces the economic burden on the healthcare system [10, p. 210].

Neuropsychiatric aspect. Vitamin D receptors are found in the hippocampus, cerebral cortex and other structures responsible for cognitive functions and emotional state. Vitamin deficiency is associated with depression, anxiety, decreased concentration and cognitive abilities [3, p. 983]. Clinical studies show that replenishing the deficiency improves the emotional state, reduces the severity of depressive symptoms and improves the quality of life of patients. This prevention is especially important for residents of northern regions and people leading a sedentary lifestyle, where access to sunlight is limited [9].

In addition, vitamin D plays an important role in the prevention of neurodegenerative diseases, including Alzheimer's disease and Parkinson's disease. It stimulates the synthesis of neurotrophic factors, maintains the health of neurons and protects them from inflammatory damage [3, p. 983]. This makes vitamin D an important element in maintaining cognitive functions and reducing the risk of age-related disorders of the central nervous system.

The prevalence of vitamin D deficiency has not only medical but also serious economic consequences. Vitamin deficiency increases the costs of treating osteoporosis, fractures, chronic infections and associated diseases. It is estimated that in Europe, the annual costs of treating and treating osteoporosis amount to billions of euros, while a significant part of these costs could be prevented through timely prevention [5, p. 1812].

One of the most effective measures is the enrichment of food products with vitamin D. Fortification of milk, margarine and vegetable oils, implemented in Finland, Canada and the USA, has made it possible to significantly reduce the prevalence of deficiency among the population without the need for mass intake of dietary supplements [4, p. 1037].

Particularly vulnerable groups remain the elderly, migrants, and socially and economically disadvantaged groups. It is among them that cases of severe vitamin D deficiency are most often recorded. State preventive programs and educational campaigns help reduce the incidence of the disease, increase awareness, and help maintain the ability to work of a significant part of society [10, p. 208].

Practical recommendations include the following measures:

*1. **Sunlight.** Spend 15-20 minutes outdoors daily without using sunscreen (depending on the season and latitude).*

*2. **Nutrition.** Regularly include fatty fish, eggs, dairy products and foods fortified with vitamin D in your diet.*

*3. **Supplements.** If there is insufficient intake of vitamin D from food and sunlight, taking supplements is recommended, especially for risk groups.*

Daily intake norms:

- children under 1 year - 400–600 IU;
- children over one year old and adults - 600–800 IU;
- elderly and pregnant women - 1000–2000 IU [10, p. 150].

When taking supplements for a long time, it is necessary to monitor the level of 25(OH)D in the blood to avoid hypercalcemia and other complications. It is important to combine prevention with physical activity and a balanced diet, which enhances the overall health effect.

The implementation of these measures will reduce the risk of diseases associated with vitamin D deficiency, improve the quality of life of the population and reduce the economic burden on the healthcare system [7, p. 756].

Conclusion

Vitamin D is a unique biologically active compound that plays a key role in maintaining human health at all stages of life. Its importance goes far beyond the traditional concept of the "bone vitamin". Modern research has convincingly proven that vitamin D has a multifaceted effect on various body systems - immune, cardiovascular, endocrine, nervous and reproductive. Deficiency of this nutrient is associated not only with classic manifestations - rickets in children or osteoporosis in adults - but also with a wide range of chronic and acute diseases, including depressive disorders, metabolic syndrome, autoimmune and infectious diseases, as well as oncological pathologies.

The biochemical action of vitamin D is realized through the activation of VDR receptors, which regulate the expression of hundreds of genes that control the processes of the cell cycle, apoptosis and the synthesis of biologically active peptides. These mechanisms allow us to consider it not just as a nutrient, but as a hormone-like regulator necessary for the normal functioning of the body.

Vitamin D deficiency is of particular importance in risk groups: children, pregnant women, the elderly, and those with limited exposure to sunlight and chronic diseases. Vitamin deficiency worsens quality of life and increases the economic burden on the health care system due to increased costs for the treatment of fractures, infections, and chronic complications. Effective measures include government food fortification programs, mass screening, and educational campaigns, which have proven their ability to reduce the prevalence of deficiency at the population level.

The complex action of vitamin D covers all the main aspects of human health: it strengthens the immune system, reduces the risk of infectious diseases, ensures the normal development of the skeletal and muscular systems, supports cognitive functions and mental well-being, affects reproductive processes and reduces the likelihood of developing chronic pathologies.

In the future, personalized medicine will be of particular importance: studying genetic polymorphisms of vitamin D receptors and individual metabolic characteristics will allow us to develop more precise prevention and treatment plans. This opens up new horizons in clinical practice and public health, increasing the effectiveness of interventions and reducing the risk of side effects.

Thus, vitamin D should be considered as a universal biological regulator, the most important factor in the prevention and therapy of a wide range of diseases. Ensuring an optimal level of vitamin D is not only a medical, but also a social, economic and strategic task. An integrated approach - rational nutrition, moderate sun exposure, the use of supplements when necessary and state fortification measures - can significantly reduce the consequences of deficiency and improve the quality of life of the population. In the future, vitamin D, due to its "non-classical" effects, may take a central place in the strategy of preventive and personalized medicine, helping to maintain health and prolong active longevity.

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Political sciences

THE STATUS OF WOMEN'S RIGHTS IN GEORGIA AT THE BEGINNING OF THE 20TH CENTURY (ACCORDING TO ARCHIL JORJADZE)

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Abstract

At the current stage, the discussion of women's rights has a universal character, which to some extent stems from the existing difficult background. The situation is aggravated by data on violations of women's rights by state. Among them, in Georgia, domestic violence against women, barriers to economic and career advancement, legal protection of women, improving access to political participation, and others still remain challenges.

In Georgia, during the period of the First Democratic Republic, which, although it existed for a short time (1918-1921), left an indelible mark on the country's history, because these three years left behind a model of a model state, where the civil and political rights of all citizens were equally ensured, regardless of nationality and gender.

Accordingly, despite the interest in the issue and political heritage from the beginning of the last century, the current situation is not very favorable. In order to improve women's rights and involvement in politics, as many researchers believe, studying/sharing past experiences is very relevant.

In addition, a number of facts confirm that this is one of the issues that is considered a prerequisite for a democratic society. The purpose of the presented work is to pose a problem that existed in the past, with the correct political understanding, and to present the possibility of solving it, which is to offer a certain opportunity to the future generations of the country to build a democratic, such a state where there will be a great effort to fully protect the rights of each citizen, regardless of language, gender, religion. In addition, everyone will have the opportunity to develop. Ar Jorjadze's political thought is one of the best examples of this.

Introduction

The theory of the development of gender inequality begins with the hypothesis that traditional society is characterized by sharply differentiated gender roles, which prevent women from working outside the home (United Nations, 2010). Various demographic, sociological, anthropological and social psychological studies demonstrate that gender roles change with the modernization of society (Ghvinianidze, Menabde, 2014).

At the current stage, when we often hear about the active involvement of women in political life. We cannot calmly face the fact that Georgia is among the countries with the lowest rate of women's representation in the Georgian Parliament and that the inadequate representation of women poses a serious threat to the democratic development of society, while the systematic involvement of women contributes to the strengthening of political efficiency and the expansion of the political agenda. This has been repeatedly mentioned at the events of a number of international and local organizations, which serves to eliminate the shortcomings existing in the Georgian political space.

When discussing these issues, it was natural for us to recall the experience of our political life. The fact that long before the legislation of a number of modern developed countries allowed women to vote, from which we, of course, today gladly accept recommendations and cooperate in their implementation, almost a century ago we had female representatives in the Constituent Assembly of Georgia (1919). This gives us the right to be more demanding of ourselves. Let us remember and learn from our worthy ancestors what was an example for other countries at that time.

It is a fact that the issue of equality has been a subject of public judgment in Georgia since the 70s of the nineteenth century. There was a wide polemic in periodicals on the "mother's question".

That is why we will now discuss Archil Jorjadze, one of the worthy representatives of Georgian political thought at the end of the 19th and beginning of the 20th centuries and a mamulishvili, in relation to women's rights. Moreover, his views have not lost their relevance even today and respond to modernity. Although many researchers have expressed their own opinions on this issue (Lobzhanidze, 1989), we consider it desirable to discuss it, given the relevance of the issue and the general scope of our research interests.

The aim of the paper is to present a general picture of the views on the rights of women in Georgia at the beginning of the 20th century, by discussing the opinions of A. Jorjadze, and to determine whether the current situation practically corresponded to the existing political provisions regarding equality. Moreover, at the modern stage, the fact that equality is one of the important prerequisites for the establishment of democracy and is also an obligation under a number of local and international documents no longer needs to be proven (Chanturidze, S., 2018).

The status of women's rights in Georgia at the beginning of the 20th century

Women's involvement in public/political activities in Georgia existed before the Democratic Republic of Georgia. A clear proof of this is the active work of women in the "Society for Promoting Literacy among Georgians", some of whom were also honorary members of this society (1879-1927). They were involved in the newly formed national educational system in Georgia at that time, namely in libraries, schools, and various institutions, thus leaving an indelible mark on both the cultural-educational and political arenas of the country (Abdaladze, 2020).

At the end of the 19th century and the beginning of the 20th century, Archil Jorjadze did not shy away from actively discussing the decline of Georgian society. He published a number of interesting letters in the Georgian press and later in his works (volumes 1, 2, 3, 4, 5), where the main place was devoted to the growth of national-political self-consciousness. "In the course of the 20th century, it will finally be clear whether the Georgian people will survive or not and whether the Georgian intelligentsia will emerge as the guardian-guardian of the "right of the nation" and the "unity of democracy," wrote Archil Jorjadze (Jorjadze, 1911,3).

It is important that Archil Jorjadze realistically assessed the impact of the current political situation on women. In particular, in the article "Musaifi" ("Woman-Man?!", 1910), he discussed the dignified behavior and strong character of Georgian women who had sacrificed themselves for the nation in the past, and then conveyed to us the bitter influence of the political "regime" on them, which presented women as victims of reality. In the language of a friend, he lamented that "Georgian women are ashamed of the Georgian language, although many of them are no longer able to speak it, but it is not they who are ashamed, but those who speak Georgian and have not yet forgotten it" (Jorjadze, 1911, 234). Naturally, he was troubled by reality, based on his national views, because due to the political situation in Georgia, the local Georgian language was replaced by Russian, which, unfortunately, had become a part of Georgian life. In the family, this was done precisely through the woman, who was convinced that Georgian was completely incompatible with the happy future of her children (Jorjadze, 1911, 237)

Archil Jorjadze, in his essay "Economic Isolation and National Unity" (January 1902), discussed the negative impact of "economic isolation" existing in the life of the nation on the integrity of the nation, pointed out its vicious influence on the violation of women's rights, and also noted the severe, limited rights of women caused by the social system. In particular, he noted: "In addition to other expenses and expenses that the peasant incurred for the benefit of his master, he was not free in his private life either... In order for a peasant's widow to get married, she had to give money to her husband's master, as much as possible, up to 10-50 rubles ("widow"). In addition, he had to pay the peasant money at the time of her marriage ("sachekme")" (Jorjadze, 1911, 197).

Archil Jorjadze supported all the opinions expressed regarding the improvement of the status of women and the expansion of their rights, which were actively published in the Georgian press at that time. In his letter - "The Sixties" he discussed N. Nikoladze's optimistic letters towards women, as well as translations by Georgian women, the letter of the young writer N. Inashvili - "The Liberation of Women" and his translation with the same title ("The Liberation of Women", 1869, magazine "Mnatobi", letter from John Stuart Mill's wife). Archil Jorjadze, after discussing N. Inashvili's letter, which stated: "Society should not create obstacles for women in their development and they should be given the same freedom as men" (Jorjadze, 1914, 138). In his letter, he noted that he fully agreed with the author and the feminist movement as a whole in many ways. Moreover, considering equal rights for men and women and providing them with certain conditions for receiving an education to be an urgent need, she added: "It is necessary to open the door to the sphere of civil and political life for women. This is an indisputable truth, which the twentieth century shamefully opposes" (Jorjadze, 1914, 140).

His letter "Woman's Sorrow" published in 1911 is important. In it, the author welcomed the recent advancement of women's issues and the activation of women in general, noting that if previously you could count the number of Georgian women studying at higher education institutions on your fingers, now their number has noticeably increased. In this letter, he discussed Ibsen's "The Sea Woman," where he criticized the family, which was presented as an arena of debauchery without love (Jorjadze, 1911, 112).

Archil Jorjadze opposed the modern family, where he considered the distribution to be unequal in every way from a legal point of view: "Today's family is a union where legal, political, and material advantages are not distributed equally. This inequality became particularly acute during the nineteenth century, when the importance of property rose noticeably and its place in the social struggle became visible. The "owners" became the masters of this country, and women, deprived of property and economically enslaved, were created as the property of the same owner.

"This happened in the upper strata of society, while in working-class circles the influence of capital on the family and the fate of women was stronger. In the form of a factory, it broke up the family and took possession of both husband and wife separately" ((Jorjadze, 1911, 118]. Therefore, he linked the women's question with the social question and considered the socialist system as a means of resolving the issue. In addition, he believed that the environment was precisely the determining factor in the increase in the number of feminist women.

Archil Jorjadze tried to formulate the "mother thought, the vein of the women's issue", here he saw three ways for women's emancipation: "1. The acquisition of a masculine personality and intellectual culture. This is how the feminist movement will move forward. There should be no difference between women and men. The equality of the sexes is an ideal. But the dream of feminism has no basis, the equality of rights does not lead to the equality of personalities, as I said, it is prevented by the difference in sexual organization and psyche, since intellectual activity and sexual passivity contradict each other. 2. Deepening the feminine personality and searching for the quality of self-determination in it, walking this path does not give a woman the power of an independent personality, because here too the temperament and passivity of a woman remain unchanged, and therefore her intellectual temperament will remain unchanged. This does not solve the issue of women's liberation, therefore it is necessary to find and study a third path: 3. Overcoming sexuality and controlling sexuality. This is a metaphysical-religious solution to the problem. This cannot be implemented in empirical reality, and the victory of this philosophy will herald the death of physical life. This solution to the problem is possible only for religious and metaphysical thinking and spiritual disposition, and for those who are not imbued with this worldview, every word and participation in this philosophy is lifeless and dead" (Jorjadze, 1911, 132). He thought that due to the complexity of the problem, his reasoning might not have shed light on it, but he tried to convey the complexity of the issue and that a superficial attitude towards this issue was harmful, both for women and for the development of culture.

From the end of xix century and beginnings of xx famous Georgian debater and patriot Archil Jorjadze's views about women rights, never has losted its popularity.

Archil Jorjadze among his life was talking and debating about women's rightful place in our community and equity. He was criticizing politics for its disbalance between men and women. He was describing a new face of woman as a citizen and mother.

Conclusion

From a number of materials discussed in the paper, it can be seen that at the beginning of the 20th century, political and public opinion in Georgia was already quite well prepared to put the issue of the need to improve women's rights on the agenda, which was later reflected in legal acts and the constitution, in the development of which women themselves were involved.

The fact is that at the turn of the 19th and 20th centuries, Ar Jorjadze actively raised the issue of women's emancipation; he repeatedly touched upon the need to improve the rights of women; he supported and welcomed the activation of the issue of women's education; he criticized the bitter influence of the political regime on Georgian women, as well as the lack of rights of women established by the social order; he saw the right way to regulate the issue in the need to change the social environment.

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Technical sciences

SOFTWARE TOOL FOR SIMULATING THE PERFORMANCE OF HYBRID PV SYSTEMS WITH STORAGE

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Abstract

This paper examines the challenge of electricity storage, a key component in the integration of renewable energy sources and the stabilization of power grids. Electricity storage also stands as a fundamental pillar of the global energy transition towards renewable and sustainable resources. As modern society grows increasingly dependent on electricity, and renewable sources – such as solar and wind power – become more widely adopted, an essential challenge emerges: the efficient storage of generated electricity to ensure availability when required. The paper presents several mathematical models developed to describe the behavior of electricity storage systems and includes simulations of the operation of an 18 kW photovoltaic system connected to different storage technologies.

Keywords: renewable energy, energy storage, hybrid system, simulation software

Introduction

Electricity storage is essential for the integration of renewable energy sources and for maintaining grid stability. It also represents a fundamental pillar of the global energy transition towards renewable and sustainable resources. As modern society becomes increasingly dependent on electricity, and renewable sources – such as solar and wind – are used more widely, a major challenge arises: the efficient storage of generated electricity to ensure its availability when needed.

This objective underpins the development of storage technologies, which make it possible to balance supply and demand, ensure a reliable energy system, reduce losses, and integrate renewable sources effectively into distribution networks. Without adequate storage capacities, power grids remain vulnerable to fluctuations in production, especially in the case of renewable sources that depend on weather conditions.

Energy storage is not merely a technological solution, but a strategic necessity in today's context. The main reasons supporting this statement include:

- Intermittency of renewable sources: solar panels do not generate electricity at night, and wind turbines operate only when wind is available.*
- Reducing the risk of outages: storage systems can supply energy in case of faults or blackouts.*
- Optimizing consumption: energy can be stored during low-demand periods and used during peak demand, helping stabilize prices and improve grid efficiency.*
- Energy independence: households and industries can become more autonomous from centralized grids.*

Types of Energy Storage Solutions

Modern energy storage technologies include a wide range of methods, each with specific applications, advantages, and limitations [1]. The most widely used are:

Electrochemical Batteries

The most common in residential and industrial applications.

- Lithium-ion (Li-ion): the most widespread technology. Advantages: high energy density, long lifespan, high efficiency (~90%).*
- Lithium-iron-phosphate (LiFePO₄): safer and more durable alternatives.*
- Lead-acid: low cost, but lower efficiency and durability.*
- Sodium-ion and other emerging batteries: alternatives to Li-ion, still under development.*

Mechanical Storage

These use physical principles to store energy:

- **Pumped Hydro Storage:** water is pumped into a high-altitude reservoir and released to generate electricity. The most widely used large-scale method.
- **Flywheel Energy Storage:** kinetic energy stored in a rotating mass. Very fast response, but limited capacity.
- **Compressed Air Energy Storage (CAES):** air is compressed and stored in underground caverns, then released to generate power.

Thermal Storage

Energy is stored in the form of heat:

- **Molten salts** (used in solar thermal plants): can retain high temperatures for hours.
- **Solid-state thermal batteries:** store energy in solid materials (e.g., concrete, ceramics).
- **Phase Change Materials (PCM):** rely on materials that change state (e.g., solid-liquid).

Chemical Storage

Energy is converted into fuels:

- **Green hydrogen** (via electrolysis): renewable electricity is used to split water into hydrogen and oxygen. Hydrogen can then be stored and reused.
- **Power-to-Gas:** electricity is transformed into synthetic gases, such as methane.

Hybrid Technologies

Systems combining multiple storage types, such as batteries + hydrogen or batteries + flywheel, to provide greater flexibility.

A comparison of the most widely used electricity storage technologies, in terms of storage cost per kilowatt-hour (kWh), is presented in Table 1.

Table 1.

Cost comparison of major electricity storage technologies

Tehnology	Estimated Cost(€/kWh)	Lifetime (cycles)	Notes
Lithium-Ion Batteries	100 – 200	3.000 – 8.000	Used in electric vehicles and for.
Lithium-Iron-Phosphate Batteries	80 – 180	4.000 – 10.000	Safer, with longer lifespan.
Lead-Acid Batteries	100 – 250	500 – 1.000	Old technology, low initial cost, but low efficiency.
Thermal Storage (Molten Salts)	150 – 400 45 – 120	>10.000 >30 years	Used in solar thermal power plants.
Pumped Hydro Storage	50 – 130	>30 years	Low long-term cost, but requires suitable terrain..
Green Hydrogen (Electrolysis)	150 – 300	5.000 – 10.000	High potential, but currently low efficiency and high costs.

Modeling of Electricity Storage Elements for a Hybrid Energy System

The modeling of electricity storage systems is a complex and interdisciplinary topic involving electrical engineering, energy systems, mathematical modeling, optimization, and, in some cases, artificial intelligence.

Modeling involves describing the electrical and chemical behavior of a storage system through differential equations and analytical functions, in order to simulate:

- The evolution of voltage over time
- The State of Charge (SOC)

The SOC is expressed as a percentage (0–100%) and indicates the level of available energy. Its evolution is defined by the equation:

$$SOC(t) = SOC(0) - \frac{1}{C_{nom}} \int_0^t i(T) dT \quad (1)$$

where:

- $SOC(0)$ – initial state of charge
- C_{nom} – nominal battery capacity (Ah)
- $i(t)$ – terminal current (positive during discharge)
- Terminal voltage as a function of load current
- Internal losses and resistive/capacitive effects

General Models

- Energy-based model:

$$E(t) = E(t_0) + \int_{t_0}^t (P_{in}(t) - P_{out}(t)) dt \quad (2)$$

- Efficiency:

$$P_{out} = \eta \cdot P_{in} \quad (\text{for charge/discharge}) \quad (3)$$

where:

- E – stored energy
- P_{out} – energy available for discharge
- P_{in} – energy used for charging
- H – storage system efficiency

Battery-Specific Models

- *Equivalent Circuit Model (RLC or RC):* represents internal behavior through resistances and capacitances.

- *State of Charge (SOC) Model:* represents the level of available energy as a function of current intensity, expressed as a percentage.

Simulation Environments Used for Modeling

- MATLAB/Simulink – widely used for dynamic and control models.
- PSCAD, DigSILENT PowerFactory – for integration into electrical networks.
- HOMER, OpenDSS – for economic and grid studies.

Optimization of Storage System Operation

Objective functions:

- Maximizing profit
- Minimizing energy cost
- Reducing emissions

Optimization techniques:

- Linear and nonlinear programming
- Genetic algorithms
- Dynamic programming
- Machine learning (for forecasting and decision-making)

Integration of Electricity Storage Systems into Power Grids

- Consumer level (behind-the-meter): self-consumption, backup supply
- Grid level: support for smart grids, resilience improvement
- Large scale: battery farms (e.g., Tesla Megapack, Hornsdale Power Reserve)

SIMULATIONS ON THE BEHAVIOR OF ELECTRICITY STORAGE SYSTEMS

Electricity storage elements play a critical role in distributed generation systems, particularly when these operate in stand-alone mode. The main challenge of a distributed energy system is that the demand for power (load) often differs from the generation available, creating an imbalance. If not corrected promptly, this imbalance can lead to negative effects that may endanger both consumers and generators.

This difference between available and required power can be addressed in several ways. Some system designers use excess power dissipation on resistors, with the energy either used for heating or wasted. Another, more efficient approach is the use of storage systems. During energy deficits, storage devices can inject power into the grid, and with proper capacity design, an efficient system can be created that continuously meets consumer demand. The evaluation of battery behavior can be significantly improved through modeling and simulation [2].

Below, several MATLAB programs are presented for simulating the behavior of a photovoltaic (PV) system with energy storage.

a) MATLAB Program for Simulating an 18 kW PV System with Storage

The MATLAB simulation models the behavior of an 18 kW photovoltaic system connected to four types of storage:

- Lithium-ion (Li-ion) battery
- Lead-acid (Pb) battery
- Vanadium redox battery (VRB)
- Proton-exchange membrane fuel cell (PEMFC)

Program structure:

- Definition of the PV system
- Technical parameters for each storage system
- Dynamic simulation over one or several days
- Comparative graphs for different storage types

Simulation inputs and outputs:

- Input: PV production (hourly profile over one or more days)

- Output: evaluation of each storage system based on SOC (State of Charge), efficiency, and capacity

- Performance comparisons of stored/delivered energy

Simulation description:

- PV generation: 18 kW, modeled as a daily sinusoidal profile

- Constant load: 3 kWh/hour

- Four storage systems modeled (Li-ion, Pb, VRB, PEMFC)

- SOC evolution plotted for each system

- Unified graph showing:

- PV power generation

- Consumer load

- Power delivered by each storage system

Results:

The graphical results obtained using the simulation program are shown in Figure 1 and Figure 2.

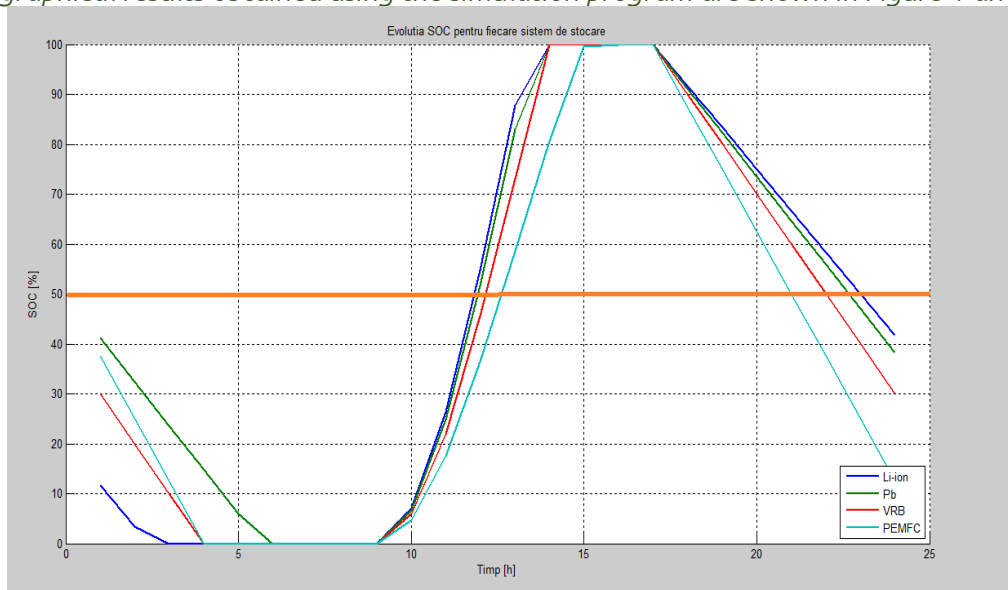


Figure 1. SOC of storage systems over time

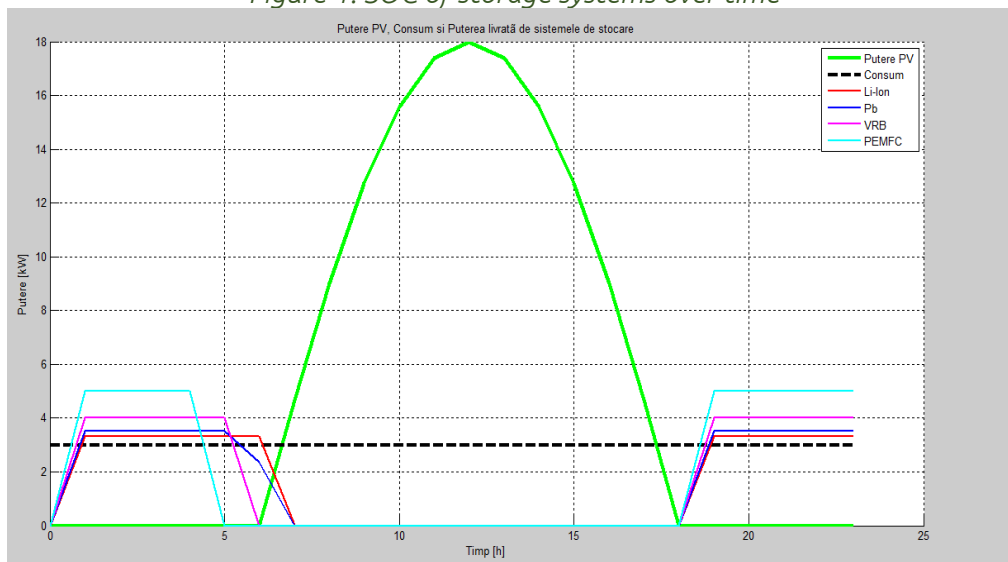


Figure 2. PV power, load, and delivered storage power over time

From Figure 1, it can be observed that the Li-ion battery has a Depth of Discharge (DoD) of 45% after 24 hours, while other storage systems show lower values. Considering that Li-ion batteries allow a minimum DoD of up to 20%, compared to 50% for the others, the Li-ion battery remains the only viable storage option after 24 hours.

Figure 2 also shows that the Li-ion battery can supply energy for a longer period compared to the other systems.

Possible extensions of the simulation:

- Multi-day or real irradiance data simulation
- Prioritization algorithm between batteries
- Addition of an inverter or grid connection
- Charging/discharging priority logic
- Constraints on maximum charging/discharging power per battery
- Integration with weather models for PV input

b) Simplified MATLAB Program for Storage Performance Simulation

This MATLAB simulation compares the technical and economic performance of multiple storage systems connected to an 18 kW PV system:

- Li-ion battery
- Pb battery
- VRB battery
- PEMFC storage system

Simulation assumptions:

- Daily PV production: $18 \text{ kW} \times 5 \text{ h} = 90 \text{ kWh/day}$ (approx. 5 peak-sun-hours/day)
- Simulation duration: 24 hours
- Load demand: 70 kWh/day
- Storage capacity: 50 kWh
- Evaluation based on efficiency, capacity, and storage cost

Results:

- Li-ion battery
 - Usable energy: 45.0 kWh
 - Remaining after one day: 18.0 kWh
 - Estimated cost: €15,000
- Pb battery
 - Usable energy: 40.0 kWh
 - Remaining after one day: 16.0 kWh
 - Estimated cost: €10,000
- VRB battery
 - Usable energy: 37.5 kWh
 - Remaining after one day: 15.0 kWh
 - Estimated cost: €35,000
- PEMFC system
 - Usable energy: 30.0 kWh
 - Remaining after one day: 12.0 kWh
 - Estimated cost: €45,000

The graphical representation of the simulation of the technical and economic performances of the lithium-ion battery storage system, lead battery, vanadium redox battery, proton exchange membrane cell storage system connected to an 18 kW photovoltaic panel system is shown in Figure 3.

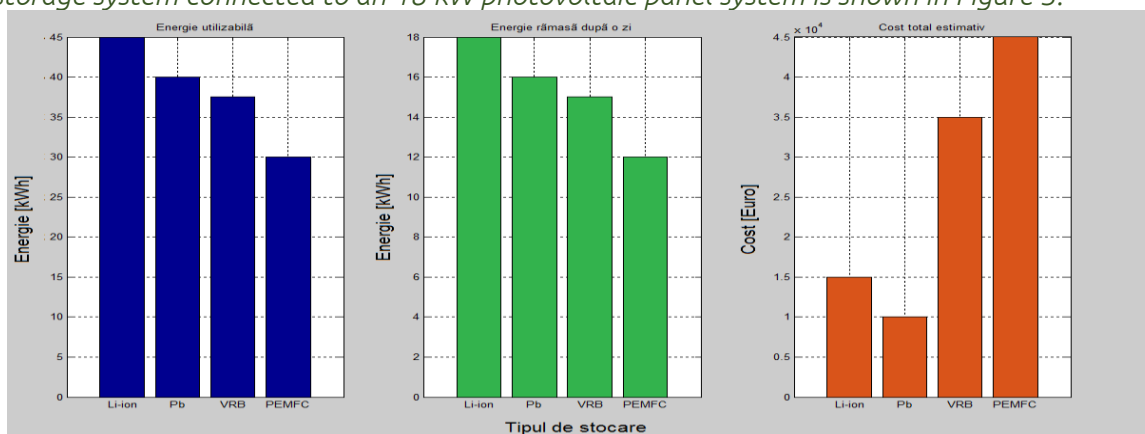


Figure 3. Illustrates the comparative technical and economic performance of the four storage systems connected to the 18 kW PV system.

Analysis of the results shows that the Li-ion battery has the highest efficiency (90%), a moderate cost (€15,000), lower than VRB (€35,000) and PEMFC (€45,000), and slightly higher than Pb (€10,000). This makes Li-ion storage the most balanced option, combining efficiency with reliability.

CASE STUDIES OF ELECTRICITY STORAGE*Hornsedale Power Reserve – Australia (Li-ion batteries) [3]*

- **Technology:** Lithium-ion battery (Tesla, software by Neoen)
- **Capacity:** 150 MW / 194 MWh
- **Location:** South Australia
- **Purpose:** Grid stabilization and peak energy supply
- **Results:**
 - Reduced grid balancing costs by tens of millions of USD annually
 - Response time in the order of milliseconds
 - Became a benchmark model for national-scale battery integration

Bath County Pumped Storage Station – USA (pumped hydro storage) [4]

- **Technology:** Pumped hydro storage
- **Capacity:** 3,003 MW (largest worldwide)
- **Location:** Virginia, USA
- **Purpose:** Long-term storage and load regulation
- **Results:**
 - Provides balancing for millions of households
 - Operating since 1985 with high efficiency (~80%)

Moss Landing Energy Storage – California, USA [5]

- **Technology:** Lithium-ion batteries (Vistra Energy)
- **Capacity:** 400 MW / 1,600 MWh (under expansion)
- **Location:** California, USA
- **Purpose:** Store surplus renewable energy, supply during peak demand
- **Results:**
 - Helps manage excess solar energy during the day
 - Reduces reliance on gas-fired plants

Goldisthal Pumped Storage – Germany [6]

- **Technology:** Pumped hydro storage
- **Capacity:** 1,060 MW
- **Location:** Thuringia, Germany
- **Purpose:** Grid support and wind energy integration
- **Results:**
 - Part of Germany's Energiewende (energy transition)
 - Provides high flexibility in frequency regulation

Tesla Powerwall – Residential Applications [7]

- **Technology:** Lithium-ion
- **Capacity:** ~13.5 kWh per unit
- **Users:** Individual consumers (households, small businesses)
- **Purpose:** Self-consumption, backup, energy independence
- **Results:**
 - Widely deployed in the USA, Australia, Germany, and beyond
 - Enables off-grid operation and lower electricity bills

Monsson – 2 GWh Project in Constanța, Romania [8]

• **Description:** Romanian renewable energy developer Monsson proposed a 2,016 MWh battery storage project in Constanța County.

- **Technology:** Battery Energy Storage System (BESS) with proprietary water-cooling solution.
- **Status:** Under environmental permitting.
- **Purpose:** Renewable integration and grid balancing.

Hidroelectrica – 72 MWh Project at Crucea Nord, Romania [9]

• **Description:** Hidroelectrica, Romania's largest renewable energy producer, launched its first battery storage project (72 MWh) at the Crucea Nord wind farm in Constanța County.

- **Technology:** Lithium-ion batteries supplied by Prime Batteries Technology.
- **Objective:** Enhance grid flexibility and integrate renewable energy efficiently.

204 MW Battery Storage Project – Satu Mare, Romania [10]

• **Description:** A 204 MW battery storage project is planned near Roșiori, Satu Mare County.

• **Status:** Approved by the National Environmental Protection Agency, with no environmental impact assessment required.

- *Purpose: Support decarbonization and renewable integration.*
Tarnița-Lăpușești – 1,000 MW Pumped Hydro Project, Romania [11]
- *Description: Planned as Romania's largest pumped hydro power plant, with a capacity between 500 MW and 1,000 MW.*
- *Location: Someșul Cald River, Cluj County.*
- *Status: In feasibility study and investment phase.*
- *Purpose: National grid balancing and integration of intermittent renewable sources.*
Romania–USA Collaboration on Pumped Hydro Storage [12]
- *Description: Romania's Ministry of Energy signed a memorandum with the U.S. National Renewable Energy Laboratory (NREL) to cooperate on pumped hydro storage projects.*
- *Objective: Develop prefeasibility and feasibility studies for projects in the Carpathian Mountains with U.S. support.*

Conclusions

This article presented software simulations conducted in Matlab for an 18 kW photovoltaic (PV) system connected to different types of energy storage: Li-ion battery, Pb battery, VRB battery, and PEMFC storage system, designed to cover a daily consumption of 70 kWh.

The simulations revealed that the Li-ion battery provides a longer discharge period compared to the other storage types, a lower depth of discharge (up to 20% vs. up to 50% for the others), higher efficiency (at least 90%), and offers a good balance between efficiency and reliability.

From Figures 1, 2, and 3, it can be observed that the Li-ion battery achieves higher SOC values and overall better performance than the Pb battery, VRB battery, and PEMFC storage system.

KEY FINDINGS ON ELECTRICITY STORAGE

Essential for the energy transition: Electricity storage is vital for integrating renewable sources such as solar and wind, which are intermittent and unpredictable.

Grid stabilization: Storage technologies balance supply and demand, ensuring stable voltage and frequency in the power grid.

Technological diversity: Multiple storage options exist (Li-ion batteries, pumped hydro storage, thermal storage, supercapacitors, etc.), each with advantages and limitations depending on application, duration, and capacity.

Efficiency and costs: Although efficiency is improving, costs remain a limiting factor. However, the continuous decline in battery prices and technological innovations are making storage increasingly affordable.

Wide applications: Storage is used both at large scale (national grids) and at consumer level (residential batteries and electric vehicles).

Sustainability and recycling: A major challenge is ensuring long-term sustainability through recyclable materials and efficient battery recycling systems.

Urban importance: In urban areas, storage provides not only autonomy but also:

- *Reduced energy bills (optimized consumption)*
- *Protection against outages (off-grid backup)*
- *Participation in prosumer programs (feeding electricity into the grid and drawing from it with economic balancing).*

NATIONAL PERSPECTIVES ON ENERGY STORAGE

*Storage targets: Romania aims to reach an electricity storage capacity of at least 2.5 GW by the end of 2025 **and** over 5 GW by 2026, according to statements from the Ministry of Energy.*

Financing: The Romanian government has allocated €150 million from the Modernization Fund to support the development of battery-based energy storage systems, both standalone and integrated with renewable sources.

Energy strategy: National energy plans foresee the development of 2 GW of pumped hydro storage capacity by 2035, with the goal of replacing polluting generation capacities and increasing flexibility in the energy sector.

Acknowledgement

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022-2027, carried out with the support of MEC-ANC, project no. PN 23140103.

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ISBN



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