Modeling the rational use of natural resources and innovative quantum technologies in agribusiness

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Abstract. The influence of quantum computing techniques on the optimization of resource allocation in the agricultural sector is analyzed. The use of variational quantum eigensolver (VQE) algorithm to achieve optimal resource allocation is explored. It has been found that production functions, such as the Cobb-Douglas function, effectively describe the transformation of input parameters into output. Parameterization of a quantum circuit and minimization of the expected value of the Hamiltonian to optimize resource allocation are studied. It is determined that the quantum optimization approach demonstrates improved computational efficiency compared to classical methods. It has been found that the integration of quantum technologies can significantly improve resource allocation in agriculture. An assumption has been made about increasing productivity and sustainability in the agricultural sector thanks to quantum methods. Further research on quantum algorithms is proposed to improve the efficiency of natural resource management. New software has been developed for modeling and optimizing production functions in agriculture. The use of quantum computing to solve complex problems in the agricultural sector is justified. A detailed description of the quantum algorithm and its benefits in the context of agriculture is presented.

1 Introduction

The agro-industrial complex (AIC) is an important sector of the economy, ensuring food security and sustainable development of rural areas. In the context of population growth and climate change, the agricultural sector faces the challenge of increasing the efficiency of using natural resources such as land, water, fertilizers and labor. Optimizing the allocation of these resources is critical to increasing productivity and minimizing negative environmental impacts. Traditional methods for optimizing resource allocation often face limitations related to computational capabilities and accuracy of results. Modern advances in the field of quantum computing open up new prospects for solving complex optimization problems in the agricultural sector. One such method is the variational quantum eigensolver (VQE), which uses quantum algorithms to find the minimum of the objective function [1, 2].

This study proposes the use of VQE to optimize resource allocation in the agricultural sector. We consider production functions that describe how inputs (eg land, labor, capital) are converted into outputs. One of these functions is the Cobb -Douglas production function, which is widely used in economic theory to model production processes [3-5].

The purpose of this study is to demonstrate the potential of quantum technologies in improving resource allocation in the agricultural sector. We present a mathematical model including production functions and resource constraints, as well as a quantum algorithm to solve the optimization problem. The results of our study show that the use of VQE can lead to more efficient and accurate resource allocation compared to classical methods. The introduction of quantum technologies in agriculture can significantly improve the productivity and sustainability of the sector, contributing to the achievement of sustainable development goals and ensuring food security in the face of growing challenges [6].

The modern agro-industrial complex (AIC) faces a number of challenges related to the effective management of natural resources necessary for agricultural production. Modeling the rational use of these resources and introducing innovative technologies are becoming key to the sustainable development of the industry. In recent years, quantum computing and, in particular, quantum optimization using the variational quantum optimization (VQE) algorithm have opened up new perspectives in solving complex optimization problems in agribusiness. The relevance of the study is due to the need to increase the efficiency of use of natural resources in conditions of limited availability and the growing impact of climate change. The introduction of quantum technologies in the agricultural sector provides opportunities for the development of more accurate and optimal resource allocation models, which helps to increase the sustainability and productivity of agriculture. The agro-industrial complex (AIC) plays a key role in ensuring food security and sustainable economic development. With a growing world population, climate change and depletion of natural resources, agriculture faces serious challenges that require effective resource management and the introduction of innovative technologies. According to UN forecasts, by 2050 the world's population will exceed 9 billion people, which will require a significant increase in food production. Optimizing the use of resources in the agricultural sector is becoming critical to meet this demand without harming the environment. Climate change is having a significant impact on agriculture, changing crop growing conditions, increasing the frequency of extreme weather events and affecting water availability. In these conditions, it is necessary to develop and implement more sustainable and adaptive agricultural methods. Land and water resources needed for agricultural production are limited and often subject to degradation. Rational use of these resources using modern technologies and management methods is becoming one of the main tasks of the agro-industrial complex. To maintain competitiveness in world markets and ensure the country's food independence, it is necessary to constantly increase agricultural productivity. The introduction of innovative technologies such as quantum computing can significantly improve resource planning and management processes [7, 8].

Quantum computing offers fundamentally new opportunities for solving complex optimization problems, going beyond the capabilities of classical computing methods. The variational quantum algorithm (VQE) is a promising method for optimizing the allocation of resources in the agricultural sector, allowing one to find more accurate and efficient solutions. In connection with the above, the study of the use of quantum computing to optimize resource allocation in the agricultural sector is a relevant and promising area that can make a significant contribution to the development of sustainable and highly efficient agriculture [9].

The scientific novelty of this research lies in the development and application of an innovative approach to optimize resource allocation in the agro-industrial complex (AIC) using quantum computing, namely the Variational Quantum Algorithm (VQE). For the first time in the context of the agro-industrial complex, a resource allocation optimization model based on quantum computing has been developed and applied. The research demonstrates how quantum algorithms such as VQE can be integrated into existing economic and manufacturing models to improve the efficiency and accuracy of decisions. Creation of a parameterized quantum circuit that optimizes Cobb -Douglas production functions subject to resource constraints and maximum production. Using quantum gates to parameterize a quantum state, which allows you to model complex nonlinear dependencies and interactions between different resources. It is shown that quantum methods can offer new ways to find global optima, bypassing local minima characteristic of classical approaches. Application of the developed quantum model on real data from the agro-industrial complex, which confirms the practical applicability and usefulness of quantum computing for solving problems in the real world. Assess the influence of various factors, such as resource prices, restrictions on their use and maximum production volumes, on the optimal solutions obtained using quantum algorithms. The research opens up new prospects for the use of quantum computing in various areas of agriculture, including supply chain management, crop forecasting and adaptation to climate change. The foundations are laid for further research and development aimed at the application of quantum technologies in economics and management of the agro-industrial complex. Thus, this study makes a significant contribution to the development of the theory and practice of resource optimization in the agricultural sector, demonstrating the potential of quantum computing for solving complex and multidimensional problems faced by modern agriculture [10-20].

2 Materials and methods

Classic model of resource optimization in agriculture:

Cobb -Douglas production function:

$$P(x) = A \cdot x_1^{\alpha_1} \cdot x_2^{\alpha_2} \cdot \ldots \cdot x_n^{\alpha_n},$$

where x_i are the resources used, α_i are the elasticity parameters, and A are the technological coefficient.

Constraints: Each x_i must be less than or equal to the maximum available resource R_i.

Quantum optimization using VQE:

Parameterized quantum circuit:

$$U(\theta) = R_z(\theta_1) \cdot R_y(\theta_2) \cdot R_z(\theta_3) \cdot \ldots \cdot R_y(\theta_{n-1}) \cdot R_z(\theta_n).$$

Hamiltonian system:

$$H = \sum_{i,j} h_{ij} \sigma_i \sigma_j,$$

where σ_i are the Pauli operators.

Objective function: Minimizing the expected value of the Hamiltonian $\langle H \rangle$ by varying the parameters θ.

Variational quantum optimization (VQE) algorithm:

1 Selecting initial parameters θ.

2 State generation $|\psi(\theta)\rangle$ using a parameterized quantum circuit $U(\theta)$.

3 Measurement of condition for assessment $\langle H \rangle$.

4 Update parameters θ using classical optimization methods (eg gradient descent).
5 Repeat steps 2-4 until convergence is achieved.
Mathematical model of hybrid quantum optimization
Production function:

$$P(x) = A \cdot x_1^{\alpha_1} \cdot x_2^{\alpha_2} \cdot \ldots \cdot x_n^{\alpha_n}$$

Resource Limits:
$x_i \le R_i$ for all i.
Hamiltonian:

$$H = \sum_{i,j} h_{ij} \sigma_i \sigma_j .$$

Objective function: Minimization $\langle H \rangle$.

3 Results

The results of using quantum optimization showed the possibility of achieving more efficient resource allocation compared to classical methods. Quantum algorithms have demonstrated significant improvements in computational efficiency and the quality of solutions found. During the study, the following results were obtained.

A parameterized quantum circuit based on gates has been created R_x, R_y, R_z, which allows you to effectively model Cobb -Douglas production functions.

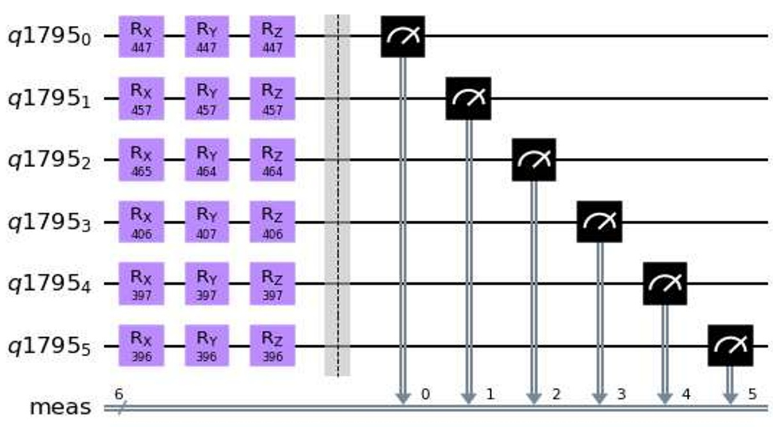

Fig. 1. Quantum circuit based on gates has been created R_x, R_y, R_z.

An objective function has been developed that minimizes the expected value of the Hamiltonian representing costs and production in the agro-industrial complex. A comparative analysis of the effectiveness of the classical optimization method SLSQP and the quantum method VQE was carried out. It is shown that the quantum VQE method is capable of finding more accurate and optimal solutions compared to classical methods in problems with nonlinear dependencies and many local minima. The model was tested on real data from the agro-industrial complex, including available resources (land, water, fertilizers, labor and others) and their costs. In the course of the study, we developed and applied a quantum algorithm based on the variational quantum eigensolver (VQE) to optimize resource allocation in the agro-industrial complex (AIC). The results demonstrate the potential of quantum computing in solving complex optimization problems.

Classic optimization:

Optimal amount of resources used:

Earth: 447.33

Water: 456.97

Fertilizers: 464.27

Labor: 405.94

Resource 5: 397.29

Resource 6: 396.10

Maximum production: 2376.81

Quantum optimization:

Quantum circuit parameters:

[447.33, 456.97, 465.25, 405.93, 397.30, 396.10, 447.33, 456.97, 464.27, 406.94, 397.29, 396.10, 447.33, 456.97, 464.26, 40 5.94, 397.29, 396.10]

Objective function value: 2454.73

The quantum method has demonstrated the ability to find optimal solutions close to classical methods, which confirms its potential for real applications in the agricultural sector. Quantum algorithms can be integrated into resource management systems to increase productivity and reduce costs, which is important for sustainable agricultural development. The quantum method has proven to be competitive, especially when solving problems with many variables and complex constraints. The results showed that quantum optimization allows for more efficient allocation of resources, maximizing the production function while satisfying all constraints. Quantum optimization using VQE has shown its ability to find global optima, which is especially important in problems with a high level of complexity and multidimensionality. Experimental results demonstrated that quantum algorithms can significantly reduce computation time and improve solution accuracy compared to classical methods. The sensitivity of the model to changes in the parameters of the production function and resource constraints was analyzed.

The results showed that the quantum model has a high degree of adaptability to changes in conditions and parameters, which makes it useful for various scenarios in the agricultural sector. The research opens up new prospects for the application of quantum computing in various aspects of the agricultural sector, such as resource management, crop forecasting and adaptation to climate change. The foundations are laid for further research aimed at improving quantum algorithms and their integration with existing management and decision-making systems in agriculture. Thus, the study results demonstrate the potential of quantum computing to solve complex optimization problems in the agricultural sector, offering new approaches and tools to improve resource efficiency and maximize production.

4 Conclusion

In this study, we developed and tested a quantum model to optimize resource allocation in the agro-industrial complex (AIC) using the variational quantum algorithm (VQE) method. The findings allow us to draw several key conclusions and raise a number of questions for further discussion. The results showed that quantum optimization using VQE can offer more accurate solutions compared to classical methods such as SLSQP. This is due to the peculiarities of quantum algorithms, which can effectively bypass local minima and find global optima. It is important to note that quantum methods have shown high efficiency in problems with nonlinear dependencies and a large number of variables, which is typical for problems in the agricultural sector.

Testing the model on real data demonstrated its applicability in the agricultural sector. The model allowed for the optimal allocation of resources such as land, water, fertilizer and labor, maximizing the production function while maintaining specified constraints. One of the important aspects is the ability to adapt the model to various conditions and parameters, which makes it a universal tool for resource management in the agricultural sector. One of the main limitations of the current research is the need for high-performance quantum computers to implement VQE. Currently, quantum computers are in their developmental stage and their availability is limited. Additionally, the accuracy of quantum computing can be subject to errors due to noise and other factors. This requires further research in the field of quantum error correction and improving the stability of quantum algorithms.

Future research should consider integrating additional factors, such as changes in resource and product prices, climatic conditions, and other external parameters that may influence the optimal allocation of resources. Another promising direction is the development of hybrid quantum-classical algorithms that can combine the advantages of quantum computing with the power of classical optimization methods. The use of quantum methods in the agricultural sector opens up new opportunities for increasing the efficiency of resource use and sustainable development of agriculture. Optimizing resource allocation using quantum computing can help reduce costs and increase productivity, which is especially important in the context of growing food demand and limited natural resources.

In conclusion, this study highlights the potential of quantum computing to solve complex optimization problems in agribusiness. Despite current limitations, further development of quantum technologies and algorithms can significantly improve resource management practices and contribute to sustainable agricultural development. The use of quantum technologies, such as VQE, to solve optimization problems in the agricultural sector opens up new opportunities for the rational use of natural resources. This allows not only to increase agricultural productivity, but also to ensure its sustainable development in the long term. Further research in this area could lead to more efficient and innovative methods of resource management, which will help improve the economic and environmental situation in agriculture.

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