

Niftiyev, Ibrahim

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The role of renewable sources in energy efficiency among agro-industrial complexes: An integrative literature review

Working Paper No. 9

Ibrahim Niftiyev ¹

² Researcher, Centre for Studies on the European Economy (AIM) - Azerbaijan State University of Economics (UNEC). AZ 1001, Istiglaliyyet str. 6.

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Ibrahim Niftiyev

ORCID number: **0000-0003-3437-9824**

Research Gate/ Google Scholar profile/Academia:

Ibrahim Niftiyev



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Abstract. Rapidly changing global economic conditions and geopolitical tensions are prompting countries to rethink their energy and food security strategies more rigorously than ever before. This urgency is particularly evident in many developing countries, especially those of the former Soviet Union (FSU), which have intensified their efforts to reconceptualize agro-industrial complexes (AICs) concerning energy efficiency and renewable energy. The aim of this study is to conduct an integrative literature review to provide a systematic and comprehensive perspective on this subject. An analysis based on the Scopus and Google Scholar databases shows that AICs have attracted considerable interest in recent years due to their potential to increase the efficiency and competitiveness of the agricultural sectors. The main issue with AICs is the urgent need to scale up their application in conjunction with sustainable development practices such as green growth, circular economy and energy transition. The integration of renewable energy sources into AICs can improve agricultural development by promoting the production and integration of sustainable energy into the agricultural sector. The literature review concludes with theoretical and conceptual implications on the studied topic that will be of interest to scholars, policy makers and businesses.

Keywords: Agro-industrial complexes, circular economy, energy efficiency, integrative literature review, renewable energy integration, sustainable agriculture, synthesis.

1 Introduction

An agro-industrial complex (AIC) combines several economic sectors and subsectors (e.g. agriculture, manufacturing) to mass produce food and consumer goods, thus ensuring food security and sustainable national agricultural production [1]. AICs are seen as an effective response to global crises and economic sanctions, satisfying domestic demand for agricultural products [1]. This concept is particularly popular in the countries of the FSU due to centrally planned and locally managed agricultural production traditions and is being further developed to address current challenges such as climate change and depletion of natural resources [2]. In various global contexts, AIC is also referred to as “agro-industrial complex,” “agro-holding complex,” “agribusiness complex,” and “farm-industrial complex.” Needless to say, the literature dealing with the complex interrelationships between AIC, energy efficiency, digitalization, green growth and rural development has multiplied, highlighting the need to keep this economic concept at the center of attention.

The above factors have led to renewable energy becoming a key driver of future sustainable development in many economies. Renewable energy sources, including solar, wind, hydropower and biomass, are increasingly favored by governments seeking to build a robust renewable energy infrastructure [3]. Despite significant efforts, challenges such as high investment costs, ongoing technical maintenance, vulnerability to external factors and instability of energy production remain [3]. Nevertheless, renewable energy represents a promising opportunity to improve energy efficiency and food production in AICs. These reasons underscore why the topic remains of great importance for ongoing research and review aimed at shedding light on recent trends and promoting future scientific exploration.

The main objective of the present research is to review the literature in an integrative way to draw a comprehensive picture of the systematic and complex nature of the relationship between renewable energy sources and energy efficiency in the context of AICs. The research question is as follows: How do renewable energy sources contribute to energy efficiency within AICs and what are the key factors that influence their integration and effectiveness? The aim of this study is to examine the dynamics between the introduction of renewable energy and improved energy efficiency in AICs and to identify the challenges and

opportunities for improving sustainability and productivity in the sector. By examining existing research, this work aims to uncover the multiple interactions and provide actionable insights for policy makers, stakeholders and practitioners involved in the transition to a more sustainable agriculture. By drawing on the most relevant literature and critically synthesizing it, the work provides a comprehensive and nuanced understanding of the interplay between renewable energy sources and energy efficiency in AICs. By systematically analyzing and integrating findings from various studies, this study provides new insights (conceptual innovation) on how renewable energy can be effectively used to improve energy efficiency in agriculture.

The main data source for this work is Scopus, and the primary methodology is an integrative literature review. Writing an integrative literature review allows researchers to synthesize findings from different sources, provide a comprehensive overview of the current state of knowledge and identify gaps in the literature. This approach enables a deeper understanding of complex topics by integrating various perspectives, which can lead to the development of more robust and innovative research questions and methods. Furthermore, the concept of AICs is gaining importance in the context of rapidly changing and evolving geopolitical conditions. This needs to be considered by key policy and decision makers in order to prepare for the new global economic order.

2 Data and methodology

In the established literature, there are several reasons for conducting an integrative literature review, primarily to explore emerging themes in greater depth and to reconceptualize mature themes [4]. In this paper, both objectives are deemed appropriate and sufficient to justify the choice of this methodology. Thus, while AIC is an established economic concept, energy efficiency based on renewable energy sources is a relatively new and emerging direction in academic research. The combination of these concepts leads to a meaningful interpretation of the research question of this paper using the integrative literature review method [4, 5].

Due to the research question and the research objective as well as the scope of the concept, this literature review is relatively short in structure and limited in content. One of the data sources for this work was the Scopus database. The main data type was published academic documents. A specific combination of search terms was used to identify the intersection of three themes: AIC, renewable energy and energy efficiency. The search terms used were: “agro-industrial complex” OR “agroindustrial complex” AND “renewable energy” AND “efficiency.” This search initially returned 12 publications published between 2018 and 2024. One conference overview was excluded due to missing authorship and relevance. The remaining documents included five conference papers, five journal articles and one editorial. The main subject areas were energy, planetary science, environmental science, economics, econometrics and finance, and physics and astronomy. Seven documents came from Russia, three from Kazakhstan and one from South Korea. All Scopus documents were in English.

The same search algorithm (“agro-industrial complex” OR “agroindustrial complex” AND “renewable energy” AND “efficiency”) was also used on Google Scholar to supplement the Scopus results, as the initial 11 publications did not appear sufficient for a comprehensive integrative review. This search yielded a further 33 publications. However, as Google Scholar does not provide finely filtered results based on search terms (e.g., Google Scholar provides results according to the search terms that also appear as a word in the reference list of publications), all 33 publications were manually reviewed and read to determine their relevance to the research objective. Consequently, one duplicate document, five non-English language documents and 21 irrelevant documents (due to significant deviation from the main aim of the research or inaccessibility) were removed from the sample. A total of 17 publications were reviewed in this integrative literature review.

The reporting does not distinguish between the Scopus and Google Scholar databases, as this integrative literature review focuses on interrelated thematic issues when it comes to the organization of the work. Following Torraco, the review process included the phases of critical analysis, synthesis, logical conclusion and reporting to ensure a comprehensive review [5]. The analytical framework of the study is shown below in Figure 1.

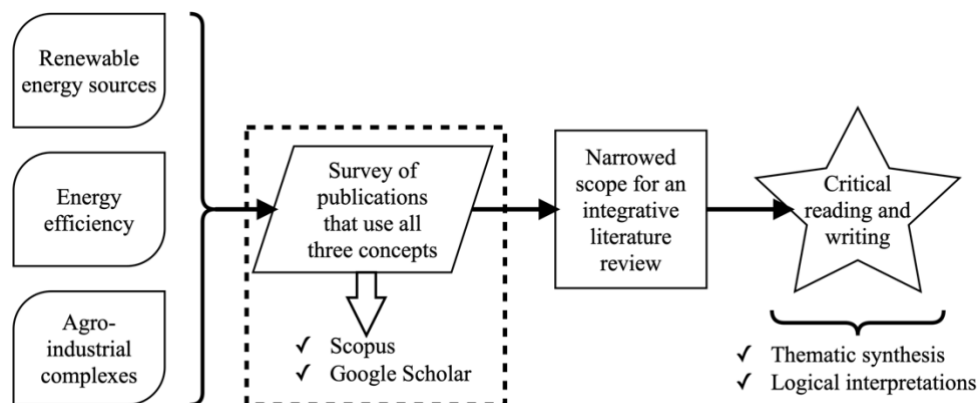


Fig. 1. Analytical framework of the current study.

3. Results

The main issue with AICs is the urgent need to scale up their application along with sustainable development practices such as green growth, circular economy and energy transition [6]. The integration of renewable energy sources in AICs can improve agricultural development by promoting agricultural production and the integration of sustainable energy into the agricultural sector [6]. However, the application of renewable energy sources in AICs is complex. First, optimization issues need to be clarified. This includes a systematic conceptualization of renewable energy sources to strive for their optimal use in a typical AIC and to organize a synthesis of this optimal use [7]. This can be achieved through theoretical and mathematical modeling that produces algorithms for autonomous areas within specific AIC zones [7]. In addition, methods based on observation and experimentation can improve our understanding of AICs and energy efficiency through renewable sources and serve as first steps to increase energy efficiency in AICs [7].

The literature on AICs, renewable energy sources and energy efficiency argues that certain renewable energy sources such as solar, wind, biomass, hydropower and geothermal can improve the competitiveness of an AIC by reducing costs and increasing energy security [8]. Currently, profitability and competitiveness are highly dependent on hydrocarbon energy sources, which lead to pollution and ecological imbalance [9]. The environmental damage caused by fossil fuels can be mitigated by utilizing renewable energy sources [9]. Most AICs in post-Soviet countries mainly rely on traditional hydrocarbon energy sources [9]. To address the global challenges related to climate change and meet domestic food needs, the energy efficiency of AICs utilizing renewable energy sources must be carefully planned and managed. The rapidly evolving technological frontiers in this field allow for a timely reconceptualization of the current situation of AICs and provide a more strategic approach to their management in the face of global challenges.

Recent trends in the global production of renewable energy sources indicate a growing industrial potential for the utilization of such sources in AICs [8]. A better understanding of

how renewable energy can increase energy efficiency in AICs will become clearer as we examine specific examples from different regions and countries.

There are various attempts to integrate new renewable sources to the AICs across the developing countries. For example, the Sukhovskoe deposit (Tomsk oblast, Russia) demonstrated a highly efficient economic and environmental results to be used thanks to appropriate fuel compositions [10]. Another study examined the Almaty region (Kazakhstan) indicating that application of digital technologies and renewable energy sources will increase the innovativeness of AICs in Kazakhstan, leading to smart agriculture practices and more efficient energy use [11]. In fact, this is a necessary step to take in the Kazakhstani economy because the domestic production in general is energy intensive and costly [11]. According to the literature, cost and environmental policies appear to be the main drivers for the integration of energy efficiency in AICs in both countries.

The experience with AICs at the subsector or crop level remains one of the main directions in the science of improving energy efficiency through renewable sources. In the Central Black Earth region of Russia, sunflower seed production has been developed as part of AICs which have led to increasing consumption of green, renewable energy [12]. Although the study by Stolyarov et al [12] is not directly in line with the focus of this integrative literature review, it shows how technical aspects of sunflower cultivation are influenced by green growth practices and energy efficiency in a typical AIC. Similarly, AIC-based rapeseed oil production is expected to move to a more sustainable and energy-efficient level [13]. Again, economic reasons such as cost and profitability appear to be the main reasons for improving agricultural production, which is positively influenced by the integration of renewable energy in AICs.

Another study identifies the main problems of agricultural energy use in the Krasnodar region of Russia and proposes the use of solar energy to solve these problems. This study emphasizes the importance of automating the assessment process for suitable locations for solar power plants using geoinformation applications [14]. The automation of territorial targeting for the optimal use of solar energy could potentially improve the efficiency of AICs [14]. Another motivation for farms or companies to introduce renewable energy technologies is the geo-optimization of AICs to increase the utility value of production.

Another study investigated the technical aspects of using energy-saving heat pump technologies with renewable energy sources to improve the efficiency of managing AICs in Kazakhstan [15]. The introduction of modular heat pumps is expected to bring significant economic and environmental benefits by reducing dependence on traditional heat sources and reducing greenhouse gas emissions [15]. This approach is a promising method for utilizing energy-efficient renewable sources to increase agricultural production in the context of an AIC. Overall, the examples of such studies emphasize that the technological design of AICs from an energy efficiency perspective remains one of the integral parts of considering renewable energy sources for agricultural production.

Although the link between competitiveness and the use of energy-efficient technologies in AICs has been extensively discussed, improvements in the use of renewable energy and energy efficiency in AICs cannot be achieved without government regulations that encourage the adoption of such technologies and influence microeconomic decisions [16]. Due to ongoing regulations and strategic planning, AICs need to convert their diesel-based plants to biofuel-based plants [17]. However, the literature shows that biofuel production facilities in most Central and Eastern European countries are not adapted to the production processes of advanced economies [18]. Government subsidies and safeguards are urgently needed to address these challenges.

Another challenging region is Almería (Spain), where high investment costs, limited knowledge transfer and insufficient support from government and industry hinder the application of energy-efficient renewable technologies to maintain high agricultural

production [19]. Similarly, farmers and other agricultural producers are expected to provide direct government funding to accelerate the whole process. These aspects illustrate the complexity of the linkages between AICs, renewable energy and energy efficiency and highlight the need for government agencies and large companies to be vigilant. This also highlights the complex spatial conditions associated with AICs.

Another interesting case study on AICs and renewable energy technologies comes from China, where the agricultural sector is crucial for economic development, food security, employment and rural infrastructure [20]. To address challenges such as labor shortages and environmental concerns, the government is promoting energy efficiency by reducing the use of fossil fuels, promoting renewable energy and advancing agricultural technologies such as solar cells, biogas and precision irrigation [20]. A study on energy efficiency in 30 provinces shows significant regional differences, with the eastern region performing best [20]. However, published academic works in China rarely considers energy efficiency in AICs, despite the increasing adoption of renewable energy technologies.

AIC is also an established economic practice in Serbia, but the country is not yet up to date in terms of renewable energy sources and technological efficiency [21]. In addition, renewable energy technologies have been successfully tested in South Korea specifically in AICs, which are promising for increasing energy efficiency through renewable sources [22].

Based on the current integrative literature review, Figure 2 illustrates the thematic, conceptual and theoretical implications between AICs, renewable energy sources and energy efficiency. This figure outlines the key trends and drivers that are likely to drive the convergence of these three concepts and accelerate their integration. These trends and drivers can be broadly categorized into six key areas:

1. Strategies and methods for integration—there is an extensive literature describing and explaining how to optimize renewable energy and revolutionize the energy efficiency of AICs;
2. Reasons for integration—this category can be understood mainly in terms of competitiveness and food security, on which various authors have conducted valuable research and made suggestions for future developments;
3. Spatial heterogeneity—the close examination of the reasons for the different experiences of countries on this theme is an ongoing trend and promises interesting future studies;
4. Subsectoral or company level urgencies—this direction includes economic, social and biological reasons why AIC, energy efficiency and renewable energy should be rapidly integrated to achieve optimization and efficiency throughout the production process;
5. Enterprise-level technological applications—this direction may include technologies to improve the day-to-day management of AICs from renewable energy and their role in increasing energy efficiency;
6. Improvements of economic legacy—this direction has been observed as an ongoing attempt to improve the inherited Soviet agricultural and industrial cooperation that was once centrally planned and locally managed.

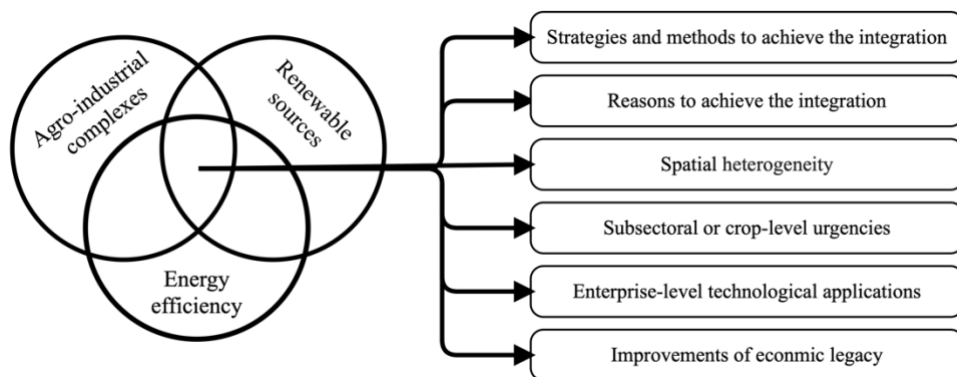


Fig. 2. Conceptual and theoretical implications based on the current integrative literature review.

Conclusions

AICs remain one of the most interesting economic entities for developing countries—especially for the countries of FSU—to ensure food security and organize agricultural production. In Western countries, this concept may have a different name (e.g., agro-industrial farms), but similar ideas can be found to use such organizational units for the common good. In the age of energy transition, achieving efficiency and increasing competitiveness is a top priority to meet global challenges and national realities. This urgency is reflected in the numerous academic publications over the last four to five years which have examined and discussed the complex integration of AICs, renewable energy sources and energy efficiency.

The main aim of this work was to apply an integrative literature review method to the Scopus and Google Scholar databases to identify the latest English-language publications. Integrative literature reviews provide a comprehensive overview of a topic by combining different research findings and making complex information accessible to a wide audience. They provide a clear understanding of the current state of knowledge, identify research gaps and point to future research directions. For this reason, this methodology was chosen to answer the research question and achieve the research objective of this study.

After analyzing 17 academic sources dealing with how energy efficiency and renewable energy interact to improve the performance of AICs, six conceptual and theoretical implications were identified: strategies and methods for integration; reasons for integration spatial heterogeneity; subsectoral or company level urgencies; enterprise-level technological applications; improvements of economic legacy. These directions suggest that AICs tend to use renewable energy technologies to increase energy efficiency in both agricultural production and in the day-to-day management of enterprises. In most publications, renewable energy is seen as the main source of energy security, and energy security can in turn lead to food security, as uninterrupted energy supply means stable agricultural production. Some papers have highlighted certain agricultural crops (e.g. rapeseed, sunflowers) that are already at the intersection of the efficiency gains associated with renewable energy in AICs.

It is interesting to observe how climate change, the adoption of sustainable development goals and the energy transition are penetrating the lives of micro-level economic actors such as AICs. The new economic realities are forcing agricultural producers to pursue several objectives simultaneously: being competitive, ensuring food security, achieving energy security and adopting the latest technologies. The future of AICs seems to be quite promising in this area of academic research, as they provide fertile ground for testing and experimenting

with newly introduced renewable energy technologies to achieve energy efficiency goals. This theme will most likely gain popularity as our planet's resources become increasingly scarce over time.

The current study had several limitations. First, there is a possibility that academic databases such as Scopus and Google Scholar did not provide a comprehensive list of publications despite the use of appropriate keywords and Boolean operators. Second, the number of search terms was limited, which may have led to the omission of relevant publications that could have been included in the analysis. Third, the small sample size could be considered insufficient given the proposed conceptual and theoretical directions. Finally, the lack of a main explanatory theory and competing ideas limited the overall integrative literature review. Therefore, the key messages of this study should be interpreted with caution and appropriate contextualization. Future research can address these challenges, and this study should be considered as a first step in exploring the indicated thematic direction.

Various country examples were outlined in this context. It should be noted that the post-Soviet countries are at the forefront of the literature on this topic. It is to be expected that in the future the experiences of Western and other countries will also be documented to develop a more holistic approach. At the same time, economic relations between FSU countries must be analyzed from the perspective of AICs in addition to ongoing trade relations [23, 24]. In addition, systematic literature reviews or bibliometric studies are appropriate methods to capture the state of the art in this field. Corporate social responsibility issues, data-driven decisions and leadership aspects should be integrated into agro-industrial complexes in the age of green transition to better understand and respond to rapidly diminishing economic resources as well [25–28]. Future studies should consider these gaps as the main motivation and inspiration for comprehensive literature reviews.

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