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INTEGRATION OF THE CIRCULAR ECONOMY INTO THE FOOD INDUSTRY

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The food industry is one of the largest consumers of natural resources and simultaneously one of the key generators of waste and greenhouse gas emissions worldwide. According to international organizations, up to one third of all food produced is lost or wasted at various stages of the “farm-to-fork” supply chain, leading to significant economic losses and environmental risks [2; 5; 6].

Under these conditions, the concept of the circular economy (CE) is viewed as a key paradigm for transitioning from the traditional linear “take–make–dispose” model to closed resource cycles, where waste is regarded as a resource and value creation is ensured through reuse, recycling, and regeneration processes [1; 6].

For the food industry, integrating CE principles produces a dual effect: first, it reduces resource intensity, food waste volumes, and environmental impacts; second, it enables the formation of new business models and competitive advantages in domestic and international markets through innovative solutions in by-product valorization, bioenergy, eco-design of packaging, and digitalized supply chains [3; 4; 19].

The objective of this paper is to summarize theoretical and methodological approaches and practical directions for integrating circular economy principles into the food industry, with a particular focus on European and Ukrainian contexts.

In its classical interpretation, the circular economy is understood as an economic model that ensures long-term preservation of resource value within the system through reuse, regeneration, and recycling, in contrast to the linear "take–make–dispose" pathway [1].

Recent review studies confirm that the food industry and agri-food supply chains are among the sectors most suitable for CE implementation, due to the large volumes of biodegradable waste, the high potential for resource and energy recovery, and the growing demand for sustainable, environmentally responsible products [2; 3; 6].

A separate dimension involves the development of an agri-food circular economy, which encompasses closed-loop biomass utilization, minimization of food waste, nutrient cycling back into soil, and integration of food and energy chains into a unified ecosystem [14].

Synthesis of scientific approaches highlights key principles for integrating CE into the food industry: prioritizing waste prevention over recycling; extending product life cycles through technological, logistical, and packaging innovations; maximizing by-product and waste utilization to obtain secondary products, biofuels, and fertilizers; and creating industrial symbioses among enterprises across agri-food sub-sectors [4; 5; 13].

In our view, the integration of CE into food industry enterprises requires the development of systematic methodological approaches that combine resource-flow analysis, circularity assessment, and strategic decision-making tools.

Based on contemporary studies, the following key stages of a methodological CE integration algorithm are proposed [2; 5; 7]:

1. Resource Flow Diagnostics (mapping flows of raw materials, energy, and water at all stages of the technological process; analyzing waste sources, composition, seasonality, and recovery potential);

2. Assessment of the Current Level of Circularity (applying Life Cycle Assessment (LCA) to evaluate environmental footprints, calculating material and energy intensity indicators, share of secondary resources, and waste recovery levels; using specialized indicators such as cycle-closure indices and processing/logistics loss metrics [7]);

3. Identification of Loss Hotspots and Circularity Opportunities (considering critical points where the largest food losses occur (storage, transportation, packaging, HoReCa, retail); identifying opportunities for internal waste processing, development of by-product lines, and collaboration with other producers and recyclers [5; 16]);

4. Formation of Circularity Targets and KPIs (setting quantitative goals for waste reduction, resource-intensity decrease, and increased use of secondary raw materials; integrating CE indicators into strategic and operational planning, including employee motivation systems [11; 19]).

5. Institutionalization of CE Processes (establishing dedicated functional units (environmental management, sustainability departments); implementing environmental management systems (ISO 14001) and food safety/quality standards (HACCP, ISO 22000) that incorporate CE components [2; 11]).

The key practical directions for integrating the circular economy into the food industry involve two main measures:

1) Reduction and Valorization of Food Waste (minimizing food waste and its market valorization form a core direction of CE implementation. Research shows that introducing "reduce–reuse–recycle–recover" strategies enables simultaneous reduction of environmental risks and improvement of economic outcomes by transforming waste into feedstock for biogas, biomaterials, animal feed, and value-added ingredients [4; 5].

Food enterprises implement solutions such as processing fruit and vegetable waste, brewer's spent grain, and whey into biogas and biofertilizers. This enables the extraction of antioxidants, fibers, and bioactive compounds from by-products for the production of functional ingredients [4]. Another measure involves organizing logistics for redistributing edible products that do not meet visual standards to charitable organizations and food assistance programs, which is also supported by European food waste reduction policies [8; 9; 10].

2) Circular business models in the food sector encompass four groups of circular business models [2; 3; 13; 19]: the resource recovery model – focused on extracting valuable components from waste and by-products; the circular suppliers model – involving a transition to raw materials and packaging made from recycled or biodegradable resources; sharing and service-based models (for example, shared use of storage and processing equipment, service contracts for waste treatment and resource recovery); and zero-waste restaurants, food service chains, and retail outlets, where waste is minimized through digital demand forecasting, menu optimization, ingredient reuse, and cooperation with recyclers [3; 6].

The implementation of these models requires a transformation in the logic of interaction among agri-food supply chain participants and the creation of circular business ecosystems, within which food enterprises may act as "anchor" companies, integrating farmers, logistics operators, processors, energy providers, and related industries around themselves [13; 14].

Contemporary research emphasizes that effective CE implementation in agri-food systems is impossible without digital technologies such as flow-tracking systems, resource-sharing platforms, digital twins, and Big Data tools for forecasting demand and losses [2; 11; 14].

According to the integration mechanism applied in the food industry, several key organizational and economic instruments can be identified. These include the development of a circular controlling system that monitors resource consumption and forms an informational basis for managerial decision-making; the integration of CE principles into enterprise investment policy (evaluation of projects considering resource-saving effects and environmental benefits); and the use of green finance instruments such as green bonds, energy-efficiency loans, and grant programs for circular projects [11; 16; 20]. Additionally, the development of cluster-based cooperation and industrial symbioses—where cross-enterprise flows of materials, waste, and energy reduce total costs and environmental impact—is of particular importance [13; 17].

In the Ukrainian context, the combination of agri-food supply chain digitalization with the development of agri-food clusters and logistics hubs aimed at reducing food losses is becoming especially relevant, particularly in export-oriented segments such as grain processing, oil-and-fat production, and dairy processing [11; 13; 14].

The European Union actively develops a comprehensive policy for CE integration into food systems through the European Green Deal, the Circular Economy Action Plan (CEAP), and the Farm to Fork Strategy [8; 16]. Farm to Fork outlines the transformation of food systems toward sustainability, reduction of resource use, pesticides, and fertilizers, as well as the establishment of ambitious targets for food waste reduction across the entire supply chain [8; 9; 20]. The proposed amendments to EU waste legislation already include targets to reduce food waste by at least 10% in production and processing, and by 30% in retail, food services, and households by 2030 [10].

For Ukraine, CE integration in the food industry occurs within the framework of EU integration commitments, adaptation to European environmental acquis, and the formation of a national strategic framework. Key documents in this sphere include the National Waste Management Strategy of Ukraine until 2030 [15]; the draft National Waste Management Plan and by-laws to the Law of Ukraine "On Waste Management" [11; 15]; as well as analytical reports and roadmaps for the CE transition developed with support from the EU, UNDP, and other international partners [11; 16; 17; 18; 20].

Several studies emphasize that effective CE integration in Ukraine's food industry requires strengthening coordination between sectoral (agricultural, industrial) and environmental policies; ensuring financial support for circular projects in the food industry (tax incentives, grants, preferential loans); and implementing European approaches to food waste reduction, eco-design of packaging, and extended producer responsibility [12; 14; 19].

Based on the analysis of contemporary international and national research, it is substantiated that the food industry possesses considerable potential for implementing circular solutions through food waste reduction, valorization of by-products, development of bioenergy, and closed-loop resource systems. The methodological integration of CE into enterprise activities requires a comprehensive algorithm incorporating resource-flow diagnostics, circularity assessment, hotspot identification, KPI formation, and institutionalization of relevant management functions. For practical CE implementation in the food industry, it is necessary to introduce circular business models, establish business ecosystems, develop digital supply chains, and apply green finance instruments, which are regulated by European policies (programs, agreements, strategies) aimed at food waste reduction and the development of a regulatory environment capable of guiding enterprises toward food system transformation while considering the realities of Ukrainian legislation. Although Ukraine is establishing the basic prerequisites for CE development (National Waste Management Strategy, legislative reforms, CE Development Strategy until 2035), full-scale integration into the food industry requires strengthening applied support instruments, financing innovations, and stimulating cooperation among agri-food chain participants.

The above aspects provide the basis for achieving positive results in applying methodological and analytical organizational-economic instruments to enhance the competitiveness of food industry enterprises under the principles of the circular economy.

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DIAGNOSIS OF THE STATE OF ECONOMIC SECURITY OF AGRICULTURAL ENTERPRISES IN THE CONTEXT OF CHALLENGES AND EXTRAORDINARY CIRCUMSTANCES

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The components of economic security form the general attributes of effective production and expansion of own resources, which ensure the activation of economic potential based on the use of the latest IT technologies with temporal and spatial dynamics. This necessitates the use of measurable indicators that allow for the assessment of exogenous (external economic conditions of agricultural enterprises) and endogenous (internal) factors of economic efficiency (the structure of the property complex, productivity, and profitability of agricultural enterprises). Therefore, the priority of our research is to increase the level of economic security of agricultural enterprises as a system that embodies a state of stable equilibrium of components in the trajectory of resource flow when the environment in which they operate changes, taking into account the restructuring of the factors affecting the security system.

The modern scientific approach to ensuring the economic security of agricultural enterprises under the influence of extraordinary circumstances is adapted to conducting a comprehensive diagnosis of its stability in relation to EU requirements and involves identifying ways to prevent or mitigate the impact of threat factors, challenges, and extraordinary circumstances in economic activity. Economic theory offers well-known approaches to diagnosing the criteria for ensuring the