WORLD STRATEGIES FOR DEVELOPING AND RETAINING HUMAN CAPITAL IN THE RENEWABLE ENERGY SECTORS: EXPERIENCE FOR NATIONAL ADAPTATION[1]

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The scientific and practical problem of substantiating the type and content of the strategy for the post-war recovery of the Ukrainian economy, as well as the mechanisms and tools for implementing the strategy, especially from the point of view of European integration, lies in the lack of a systematic approach to integrating the principles of the modern green economy of the EU into the economic policy of Ukraine. It is obvious that the strategy for the economic recovery of Ukraine requires a fundamentally new paradigm that goes beyond traditional approaches to the reconstruction of infrastructure and industry. The European Union, within the framework of the European Green Deal, has formed an innovative development model that combines economic growth, decarbonization, circular economy and social justice. At the same time, in Ukraine, the issue of implementing the principles of the green economy into the post-war recovery strategy remains conceptually and institutionally inconsistent [1]. In 2026, the global energy architecture will undergo fundamental transformations. The transition to renewable energy sources has ceased to be exclusively a technological challenge; Today, this is primarily a challenge for human capital management systems. According to IRENA, the renewable energy sector already provides more than 15 million jobs worldwide, and this figure is expected to triple by 2050. However, the main obstacle remains the "skills gap".

We consider human capital in this area as a set of knowledge, skills, health and motivation of specialists who provide design, implementation and service of green technologies. For scientific analysis, it is important to distinguish four dominant global models, each of which offers its own mechanism for reproducing this specific asset.

The European model is the most regulated and socially oriented. It is based on strategic planning within the framework of the European Green Deal and the REPowerEU initiative.

Thus, the key characteristics of such planning are the successful combination of the concept of "just transition", according to which Europe is betting on the fact that the energy transformation does not cause social collapse in traditional energy regions. In many EU-27 countries, special funds (Just Transition Fund) have been created to finance reskilling programs for workers in the coal and oil and gas industries to meet social needs when changing the country's energy policy. The European model closely links the academic environment with production. Centers of excellence - specialized hubs where students work directly with manufacturers' equipment (for example, Vestas or Siemens Gamesa) provide advanced training for specialists, regardless of the country, which ensures the free migration of capital and knowledge. Unlike the USA, where competition reigns, the European model is based on a tripartite partnership: State - Business - Trade Unions. As part of the strategy, large players (for example, "Iberdrola", "Enel") cooperate with vocational education institutions to quickly develop new training standards. The EU is implementing a unified qualification framework that allows a heat pump installer or wind turbine service technician to work freely in any EU country, which increases the liquidity of human capital. The effectiveness of such a model is manifested in the

high quality of training and the low level of resistance from trade unions, since the state guarantees the stability of jobs in the green sector. The EU considers capital formation through the prism of transversal competencies. This means that a specialist in the renewable energy sector must have not only technical knowledge (panel installation), but also digital skills and an understanding of the principles of the circular economy. The EU is actively encouraging the involvement of women in STEM professions in the renewable energy sector, which is seen as a tool for eliminating the personnel shortage and maintaining social guarantees during the transition to decentralized energy systems [2].

But each country has its own vision of the transition. For example, in the USA, the transformational course has acquired the properties of innovative-market liberalism - it is a reference system where the main driver of progress is not a state directive, but the "invisible hand of the market", reinforced by venture capital and the cult of entrepreneurship. The US model is based on the belief that the state should create a field for action (legislative infrastructure), and not be an active player. Although the model is liberal, the role of the state in the USA is specific and highly effective: the state invests money in basic research (NASA, DARPA, ARPA-E in energy), the results of which are then commercialized for free or cheaply by the private sector. As an example, the Internet and GPS were by-products of a state defense order. Instead of direct subsidies to enterprises, the USA often uses tax breaks for consumers (for example, the Inflation Reduction Act - IRA), which forces companies to compete for a real client, and not for the loyalty of an official.

In 2024–2026, the American model of transforming the strategy of forming and preserving human capital in the renewable energy sectors industry is based on the concept that the US stimulates private generation through tax credits, creating a huge market for MarTech solutions (Smart Home, virtual power plants). In turn, companies fight for ESG ratings, as this opens up access to the cheapest capital in the world on Wall Street. The US has an extremely developed system of short-term intensive courses (bootcamps) and professional certifications from technology leaders. A diploma from a classical university is often inferior in importance to a current certificate from an equipment manufacturer. Human capital in the US is formed in the startup ecosystem. The close integration of universities (MIT, Stanford) with venture capital ensures an influx of highly qualified engineers-innovators focused on breakthrough technologies (for example, carbon capture or solid-state batteries). But the weak link in this model is high social inequality and the lack of systemic guarantees for low-skilled workers.

The US model is fundamentally different from the European one. Here, the main customer and architect of human capital is the private sector, and the role of the state is reduced to creating powerful economic incentives. The European model of the strategy for the formation and preservation of human capital in the renewable energy sector (RES) is fundamentally different from the liberal American model. If the USA focuses on market mobility and individual initiative, then Europe chooses the path of a socially oriented just transition.

So, if the American model maximizes the efficiency of capital at the moment, then the European model ensures its sustainability. In the context of globalization, it is the European path that allows you to create a sustainable ecosystem, where innovations in energy are synchronized with the development of society.

So, if Europe focuses on a just transition, then Asia (in particular China, South Korea, Japan and Vietnam) focuses on scalability, speed and state discipline. The Asian strategy for the formation and preservation of human capital in the renewable energy sector is a technocratic model of vertical leap, which is fundamentally different from the liberal American and social European models due to the tight integration of education, science and state industrial policy.

In the Asian model, the state is not just a facilitator, but the main architect of the personnel order. Through centralized planning, governments define clear KPIs for the number of specialists in hydrogen energy or lithium battery production for 10–15 years ahead. In addition, the state creates technopolises and clusters (a combination of university cities integrated with industrial ones), which ensures zero lag between scientific discovery and its implementation in the curriculum.

The state here acts not just as a regulator, but as the main investor in the development of human potential. For example, China dominates the production of photovoltaic cells and wind turbines precisely thanks to the mass training of technical personnel. The state subsidizes thousands of specialized colleges that work in conjunction with gigafactories. This is a model of "vertical integration", where human capital is part of the industrial conveyor [3].

Instead, South Korea is betting on a digital green transition. Here, human capital is formed at the junction of IT and energy. Great attention is paid to training specialists in energy management, Smart Grids and Big Data management in energy systems.

Asia has bet on mass. While Europe trains high-class research engineers, China trains millions of certified technicians. The Asian model provides the lowest cost per unit of human capital with its colossal volumes, which makes these countries the production hubs of the planet. But Asian countries are actively using their diaspora in the USA and the EU to import competencies. Chinese government grants for scientists to create superpower laboratories within the country aim to bring back leading specialists from Silicon Valley. This is a key element of preserving and building intellectual capital.

So, the Asian strategy for the formation of human capital in renewable energy is, first of all, the marketing of national strength. If the European model teaches us cooperation, then the Asian one teaches us speed and scale [4].

In countries that are intensively developing, such as India or Brazil, the model of the strategy for the formation and preservation of human capital in the renewable energy sectors is based on inclusiveness and "Bottom-up" development. For these countries, renewable energy is not only an environmental issue, but also a tool for social uplift. Programs like the "National Solar Mission" in India are aimed at training residents of rural areas. Special attention is paid to women (the "Solar Mamas" projects), which allows ensuring energy autonomy in remote villages and at the same time creating jobs.

In Brazil, human capital has traditionally been developed around the biofuel sector. Skills are developed within agro-industrial clusters, where agricultural knowledge is complemented by competences in biochemistry.

Since the distributed networks in these countries are often imperfect, human capital is focused on off-grid systems, which requires specific local service skills. Comparing global strategies for the formation and preservation of human capital in renewable energy sectors, we can identify key characteristics (table 1).

Table 1. Comparative matrix of the effectiveness of strategies for the formation and preservation of human capital in renewable energy sectors

Parameter	Asian Model (State-Driven)	European Model (Social-Value)	American Model (Market-Agile)	Bottom-up model
Driver	National Competitiveness	Environmental Ethics and Human Rights	Individual Profit	Poverty alleviation
Formation Method	Directive Public Procurement	Social Dialogue	Market Demand	Population coverage
Speed	Ultra-High	Moderate	High	Low
Key Emphasis	Scalability and Exports	Sustainable Development and Inclusion	Disruptive Innovations	Social lift
Employee Role	Element of the Global Value Chain	Active Prosumer and Citizen	Entrepreneur-Innovator	High in inclusion
Strength	Social Protection	Disruptive Technologies	Scale and Price	Population coverage
Weakness	Bureaucracy	Social Inequality	System Rigidity	Lack of funding

Analysis of world models shows that in the 21st century, those economies that are capable of hybridization will win. For example, the US is beginning to borrow European elements of social support (IRA includes wage requirements), and the EU is trying to deregulate the education sector to increase American flexibility. A common feature of all successful models is the digitalization of skills, because human capital without software knowledge (SCADA, AI analytics) loses 80% of its value. The global trend in education is micro-qualifications and continuous learning. On the other hand, traditional 5-year energy training programs are becoming too inert.

Countries that combine European social guarantees with American innovation and Asian speed of scaling (such as Denmark or Germany) demonstrate the best results in the formation of high-quality human capital [5].

For countries in the process of transformation (in particular, for Ukraine), the most rational is to combine European certification standards with American flexibility of private educational initiatives and Asian speed of scaling through dual education. The future belongs not just to "green" energy workers, but to specialists whose human capital is simultaneously technological, digital and adaptive. A hybrid model for Ukraine is not just a compromise, but a strategic necessity. In a war period, when the country is actively rebuilding its energy system after destruction, copying only one approach would be ineffective. Ukraine has a unique context: a combination of European aspirations, American decentralization and the need for rapid Asian scaling.

The hybrid model "Ukrainian Energy Transition" can borrow the experience of creating energy free economic zones in China, where training is exempt from taxes on the condition of work on reconstruction. The Asian model proves that the best way for Ukraine is a strict standardization of skills and the introduction of digital management systems that reduce the requirements for the uniqueness of personnel. Ukraine can become a training ground for the whole world in the field of reconstruction after conflicts, converting its military experience into highly liquid human capital (table 2).

Table 2. Comparative architecture of the hybrid model for Ukraine

Component	What exactly are we borrowing	Expected result
Regulatory	EU Directives (Green Deal)	Compatibility with the EU network and investments
Technological	American Venture Capital Approach	Innovations in energy management (Smart Grid)
Educational	Asian Dual Education	Rapidly filling the staff shortage
Social	Inclusive Development (India)	Employment of vulnerable groups and veterans

So, we are borrowing the structure and regulations of EU standards for specialists. This allows Ukrainian engineers to be part of the single energy market. Ukraine has a powerful IT sector, which becomes the basis for "Smart Grids". Using the US experience in protecting energy facilities to create autonomous "microgrids", where human capital is focused on cybersecurity and autonomous management, will ensure the creation of conditions where private companies (and not just the state) invest in training installers and service engineers. But in order not to be just an importer of technologies, Ukraine needs elements of the Chinese model: the creation of powerful vocational schools directly at factories producing solar panels or components for wind turbines; rapid retraining courses for thousands of people, which will ensure low cost of implementing solutions [6].

Social inclusion (reintegration of veterans) is the most important component of the model of developing countries, adapted to our realities. Renewable energy is an ideal area for socialization of former military personnel. Working with drones (for inspecting wind turbines), engineering and logistics are skills that can easily be transformed into green professions. Such hybridity will allow Ukraine to be adaptive. In the event of a change in market conditions, either the market (American) or state (Asian) segment of personnel training can be strengthened. But gaps in education today are the main deterrent to the green transition. Even with the availability of investments and equipment, without qualified brains and hands, the system remains dead. The most effective tool is dual education. This is a format where a student spends 30% of his time at the university (theory), and 70% at a real VE facility. Also critically important is the creation of Micro-credentialing centers - short intensive courses that allow an engineer to obtain a specialization in 3 months, for example, in "maintenance of offshore wind farms."

Global models for building human capital in the renewable energy sector demonstrate effective approaches to training specialists, developing skills and integrating innovation into the industry. At the same time, their practical implementation highlights the need not only to create but also to retain this potential [7]. That is why the next logical step is to develop a strategy for retaining human capital in the renewable energy sector, which will ensure the retention of skilled personnel, their motivation and long-term development.

The transition to a low-carbon economy has led to unprecedented demand for specialists with 'green' skills. In the renewable energy sector, talent competition extends beyond the energy industry, encompassing IT and high-tech manufacturing. This requires developing specific incentive models that account for both the technical complexity of projects and employees' values.

Renewable energy is an industry where human capital is a strategic resource. Unlike traditional energy sectors, where tangible assets predominate, the success of renewable energy companies is determined by the

internal motivation of their staff: an awareness of their environmental mission, the social value of their work, and the technological innovation involved.

Intrinsic motivation is enhanced under three conditions: autonomy, competence and meaningfulness. For the renewable energy sector, it is the meaningfulness of work that acts as the most powerful driver of retention, innovative activity and organisational commitment. Two factors are at play in this context:

Factor 1: mission orientation. Employees increasingly perceive their professional activities not merely as the fulfilment of functional duties, but as a personal contribution to achieving broader socially significant goals, particularly climate stability and social justice. This shift in the perception of work fosters deeper intrinsic motivation and enhances loyalty to the organisation. Empirical data presented in the Deloitte Energy Workforce Report (2023) confirms this trend: companies that integrate an environmental mission into their corporate culture demonstrate a 27% lower staff turnover rate compared to the energy sector average.

Factor 2: Identification through strategy. An important factor in boosting staff engagement is their involvement in the strategic planning processes relating to the company's environmental impact. Such involvement helps to foster what is known as a 'green identity', which combines professional fulfilment with environmental responsibility. In this context, employees begin to align their own values with the organisation's goals, which minimises the risk of cognitive dissonance and has a positive impact on the level of organisational engagement [8].

The mechanism for developing a 'green identity' involves systematically engaging staff in the strategic planning of the company's environmental impact. This approach not only raises staff awareness but also fosters a sense of personal responsibility for the outcomes of the organisation's environmental activities. The mechanism is implemented across three interlinked stages.

The first stage involves integrating knowledge regarding the impact of business activities on the environment. Creating open platforms for assessing the 'carbon footprint' and the environmental consequences of project implementation helps foster environmental awareness at the level of each employee, making these issues personally meaningful

The second stage involves the joint formulation of 'green goals'. Involving cross-functional teams in the development of ESG strategies ensures that employees feel a sense of ownership over tangible changes within the company's climate policy and strengthens their involvement in strategic processes.

The third stage involves symbolic recognition of the employee's role in achieving environmental goals. Recognising individual environmental initiatives, particularly those aimed at reducing energy consumption or implementing renewable solutions, helps foster a sense of 'internal ownership' of the organisation's mission.

Ultimately, this fosters the employee's personal 'green identity' – a firm belief that their professional activities have a positive impact on the environment. It is this identity that forms the core of intrinsic motivation for environmentally responsible behaviour.

Empirical indicators show that in companies with a high 'Meaningful Work' index (according to Gallup, 2022), the average tenure of renewable energy employees is 6.8 years, compared with 4.3 years in the traditional energy sector. Engagement Index. Increases by 35–40% where programmes for collective planning of environmental strategies are in place (IEA Workforce Survey, 2023). Correlation between ESG activity and innovation [9]. Teams with a strong 'green identity' submit 22% more innovative proposals directly related to energy efficiency and decarbonisation.

Policies on staff well-being and the provision of safe working conditions in the renewable energy sector are becoming a strategic tool for the preservation and development of human capital. In the current context of the energy transition, characterised by technological turbulence, a high pace of innovation and increasing demands on staff qualifications, employee well-being is viewed not merely as a social function of the enterprise, but as a key factor in long-term competitiveness and institutional resilience.

The renewable energy sector is characterised by heightened risks in the working environment, particularly in the wind power, solar power and hydrogen energy segments, where workers are often deployed in field conditions, working at height, with high-voltage equipment or in environments of increased technical complexity. In this context, the development of a comprehensive occupational health and safety system that integrates international safety standards (in particular ISO 45001) is a prerequisite for minimising occupational risks and reducing workplace injuries. At the same time, an effective safety policy entails not only compliance with regulatory requirements but also the fostering of a culture of safe behaviour, where every employee acts as an active participant in risk management.

Well-being policy in the renewable energy sector is multi-dimensional in nature and encompasses the physical, psychological and social aspects of well-being. The physical component involves creating a safe and

ergonomic working environment, implementing programmes to prevent occupational illnesses, regular medical monitoring and promoting a healthy lifestyle [10]. The psychological dimension involves ensuring the psychological and emotional resilience of staff in conditions of high responsibility and uncertainty, in particular through the development of psychological support programmes, the prevention of occupational burnout, and the fostering of an atmosphere of trust and open communication. The social aspect relates to ensuring a balance between professional and personal life, developing an inclusive environment, and supporting teamwork.

The integration of well-being policies into the strategic human resources management system is of particular importance. The practice of leading energy companies shows that investment in well-being contributes to increased labour productivity, reduced staff turnover and greater organisational loyalty. Thus, employee well-being becomes an important intangible asset that ensures the accumulation of knowledge, the retention of critical competencies and the maintenance of the enterprise's innovative potential.

Furthermore, a policy on safe and healthy working conditions aligns with the principles of sustainable development and ESG-focused management [11]. The social component of ESG entails a company's responsibility to create decent working conditions, which, in turn, builds a positive reputation as an employer and enhances its appeal in the global talent market. In the renewable energy sector, where competition for highly skilled personnel is particularly fierce, such factors play a decisive role in ensuring long-term workforce stability.

Consequently, policies on staff welfare and safe working conditions in the renewable energy sector should be viewed as an integrated strategy for retaining human capital, combining tools for occupational health and safety, psychological support and social responsibility. Its effective implementation creates the conditions for the sustainable development of enterprises, enhances their innovative capacity and fosters the formation of resilient organisations capable of adapting to the challenges of the global energy transition.

Talent management in high-tech sectors is a critical tool for ensuring sustainable development, particularly in the renewable energy sector, where the pace of technological innovation is two to three times faster than the industry average. According to estimates by the International Renewable Energy Agency (IRENA), over 38 million jobs will be created in the 'green' energy sector by 2030, generating unprecedented demand for highly skilled professionals [12]. In this context, talent management takes on strategic importance for the formation, development and retention of human capital capable of ensuring the sector's innovative growth (table 3).

Consequently, the strategy for retaining human capital in the renewable energy sector must be based on systematic talent management focused on the continuous development of skills, the fostering of innovative motivation, and the cultivation of environmentally responsible thinking. Implementing such approaches will enable human capital to become a key asset of the 'green' transition, ensuring the sector's technological self-sufficiency and competitiveness in the global market.

An organisational culture based on the principles of sustainable development, innovation and social responsibility creates an environment in which professionals feel engaged, trusted and motivated to pursue a long-term career in the 'green' economy. The culture that fosters openness to change, the search for new technological solutions and a readiness for interdisciplinary collaboration as key components of effective knowledge management in the dynamic energy sector.

Table 3. Hypotheses regarding the impact of talent management on innovation and staff retention

Hypothesis 1: Effective talent management is directly correlated with the level of innovation activity among companies in the renewable energy sector.	Companies that implement talent development systems (individual learning pathways, technical accelerators, leadership programmes) demonstrate, on average, 25–30% higher performance in innovation projects.
Hypothesis 2: Retaining human capital in the renewable energy sector depends to a large extent on the synergy between education, science and business.	The creation of flexible educational and scientific platforms bringing together universities, research institutes and companies in the energy sector helps to reduce staff turnover by 15–20% in the medium term.
Hypothesis 3: A key factor in motivating specialists is not only salary levels but also the availability of opportunities for professional self-expression.	High-tech organisations that implement the principles of a 'green corporate culture' and social responsibility retain up to 40% more talent than companies with a traditional HR management model.

ESG approaches serve as an institutional framework that complements companies' strategic objectives with a humanistic and environmental dimension. The implementation of practices relating to environmental responsibility (E), social justice (S) and high standards of corporate governance (G) creates the conditions for building trust among employees, investors and partners. Research shows that companies with integrated ESG strategies demonstrate 20–25% lower staff turnover and higher productivity in the field of innovation.

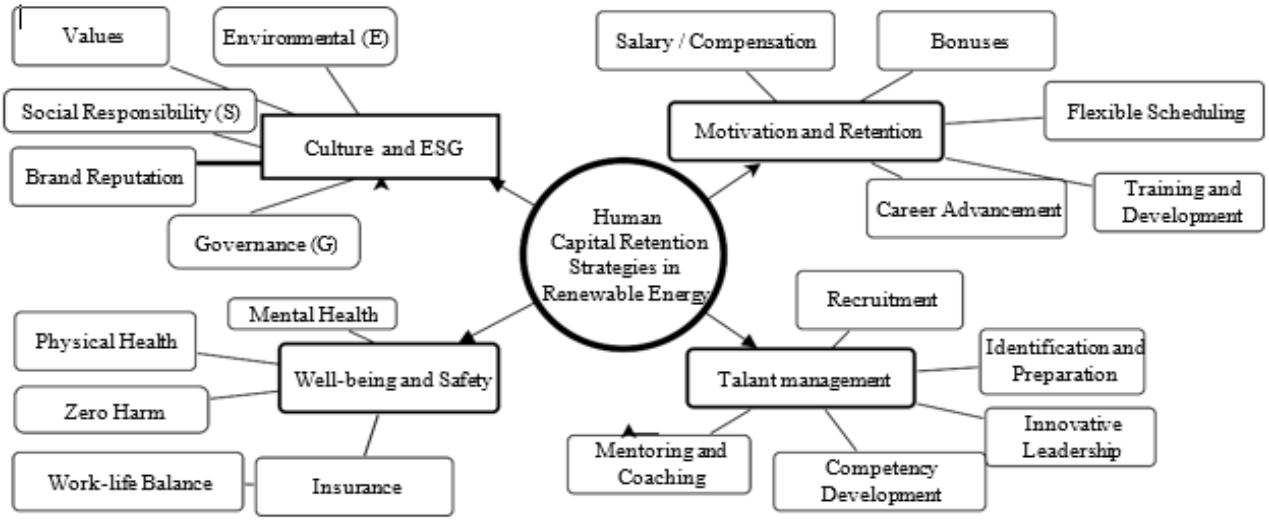

Figure 1. *A networked framework for strategies to retain human capital in the renewable energy sector*

Thus, in the context of renewable energy and human capital retention strategies, ESG approaches serve a dual purpose: on the one hand, they strengthen corporate identity and employees' ethical responsibility; on the other, they foster an attractive employer brand in the global labour market. A culture of sustainability, built on ESG principles, creates a value framework for the development of a competent, motivated and environmentally conscious workforce – a key resource for long-term success in the green energy sector.

Retaining specialists in the renewable energy sector relies not only on financial incentives, but above all on a sense of purpose in their work. When people see the contribution they are making to protecting the environment and shaping the future of energy, a deep sense of personal motivation and a natural desire to remain part of this endeavor take root.

Caring for an employee's physical and psychological well-being is an expression of respect for the individual as a key value. Safe working conditions, support for a work-life balance, and attention to emotional well-being create an environment in which people can develop steadily and work without burnout. Investments in training, professional growth and employee self-fulfilment are investments in the industry's future. People stay where they feel they can develop, realise their potential and influence innovation. An organisational culture built on trust, responsibility and environmental values fosters a community of like-minded individuals. ESG approaches not only strengthen a company's reputation but also help employees feel proud of their work and their part in an important mission.

The formation of human capital in the leading countries of the world today is based on the concept of Long-life learning and adaptability to the challenges of the digital economy. The relevance of the formation of human capital in modern conditions is due to the transition to a global knowledge economy, where intellectual potential becomes more important than natural resources or physical capital. Today, this process goes beyond classical education and is transformed into a strategic system of survival and development of states.

The relevance of the concept of human capital development in the era of global transformations is due to the need to find effective answers to the challenges of the modern BANI-world. In an environment where processes are fragile, disturbing, nonlinear and often incomprehensible, the ability to quickly retrain becomes a fundamental condition for maintaining the economic stability of both an individual and entire states. This need is reinforced by the processes of the "double transition" - simultaneous digital and "green" transformation. The introduction of artificial intelligence and the decarbonization of the economy require the formation of completely new "green" competencies that require constant updating throughout professional activity. An additional factor is demographic changes: the aging of the population in developed countries is

forcing governments to invest in “active longevity” programs and training for the 40+ category in order to maintain labor productivity in the long term.

Key approaches to ensuring high-quality human capital are currently being implemented through several strategic directions. Firstly, this is the creation of a Lifelong Learning ecosystem, where lifelong learning is transformed from a theoretical slogan into a real economic mechanism. The experience of countries such as Singapore and Finland demonstrates the effectiveness of the introduction of individual educational accounts, which allows citizens to adapt to automation without fear of losing social status. Secondly, the emphasis is shifting to adaptability to the digital economy, which involves the development of digital intelligence (DQ), in particular skills for working with Big Data, critical analysis of information and ethical interaction with artificial intelligence.

An important component is the integration along the Education - Science - Business vector, where human capital is formed at points of maximum synergy. Vivid examples are the German model of dual education, which combines a theoretical base with practice in the workplace, and American university incubators, which ensure the rapid commercialization of scientific ideas. After all, innovative sustainability increasingly depends on the development of “soft skills”. As highly technical competencies quickly become obsolete, emotional intelligence, cognitive flexibility, and cross-cultural communication skills become a priority, allowing professionals to remain effective in complex international projects and dynamic business environments. Figure 2 provides an overview of key approaches that ensure a high-quality workforce and innovative resilience for modern enterprises.

The German experience in human capital formation is a model example of how the state and business can jointly create a sustainable and adaptive economy [13]. This process is based on the deep integration of learning into the working environment and a strategic focus on energy transformation. The German approach is based on the division of responsibilities between state institutions and the private sector. This is not just formal education, but a living ecosystem of personnel training. The theoretical basis obtained in specialized schools takes up only a smaller share of the educational process. The main emphasis is on practice directly on production lines, in laboratories or offices of companies. Companies do not wait for a ready-made specialist, but “grow” him for their technical needs. The payment of scholarships to students is considered not as an expense, but as a long-term investment in the quality of their own personnel reserve. Such a model minimizes the gap between graduation from an educational institution and employment. Having received real professional skills, young specialists become competitive even before receiving a diploma. Development of intellectual potential in energy clusters. In parallel with basic education [14], Germany is actively forming human capital through specialized innovative associations focused on energy security and greening. Clusters combine the scientific potential of universities with the capabilities of large energy players. This creates an environment where scientific developments instantly become part of production processes. Much attention is paid to the formation of so-called Green Skills. This involves not only training new personnel, but also large-scale retraining of engineers and technicians from traditional industries to work with hydrogen technologies, solar generation and energy saving systems. Within these clusters, managers are trained who are able to make decisions in conditions of rapid technological change. This ensures the economy's resilience to global crises and market volatility [15].

Denmark is a world leader in wind energy, and its success is based not only on technology, but also on a unique system of training and human capital management. The Danish approach combines social stability, a flexible labor market and advanced training of specialists for the “green” sector. The foundation of human capital formation in Denmark is the Flexicurity model, which allows the country to quickly adapt the workforce to the energy transition. Employers can easily hire and fire employees, which allows businesses to quickly respond to technological changes. The state provides a high level of social guarantees and unemployment benefits, which removes the fear of changing professions. The main condition of the system is constant retraining. If an industry (for example, oil production) declines, the state and trade unions finance the training of workers for new sectors (wind energy).

Denmark was the first in the world to start mass introduction of wind power generation, which forced it to create a holistic system of development of specific skills. The city of Esbjerg is a classic example of reorientation of human capital. Previously, it was the center of the oil and gas industry, but thanks to the Offshore Academy program, the competencies of workers on offshore platforms were adapted to servicing offshore wind farms. Engineering knowledge of marine construction and safety on the water became the basis for the wind industry.

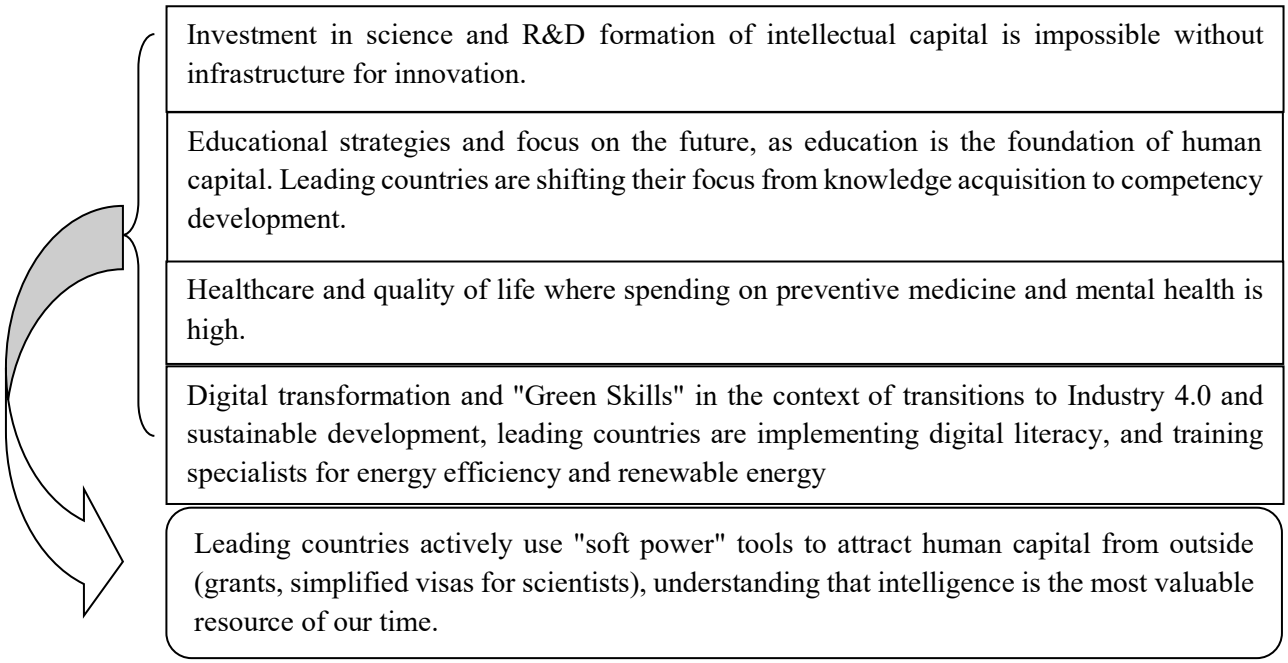

Figure 2. *Overview of key approaches that ensure high-quality workforce and innovative sustainability. Source: generated by the author [14, 16-18].*

Training is carried out with the participation of market leaders, vocational colleges and universities have joint programs with business. Students work on real facilities already during their studies. Denmark has created a network of test centers (for example, Osterild), where specialists learn to work with giant turbines even before they become serial. Lifelong learning, in wind energy technologies change every 3–5 years. The Danish system supports “competence mobility”. A mechanic who has worked with car engines can take a state course and receive a certificate as a specialist in servicing wind turbine gearboxes. Environmental thinking and digital literacy are integrated into all levels of education, from schools to vocational courses.

China's human capital formation strategy is aimed at fundamentally transforming the country into a global innovation hub. The state considers the development of human resources as a national security priority, which is confirmed by stable investments at the level of 4% of GDP. Through the "Dual First-Class Status" program, China is creating a world-class university network, which should become a leading educational hub by mid-century. The main vector of education has shifted towards STEM disciplines, which has allowed the country to take first place in the world in the number of trained engineers and scientists. Special attention is paid to the introduction of courses in artificial intelligence, robotics and big data into curricula at all levels. In parallel, an aggressive repatriation policy is in effect, in particular the "Thousand Talents" program, which stimulates the return of leading scientists from abroad through the provision of large-scale grants and laboratories. In the field of vocational education, China is implementing the "Smart Manufacturing" reform, creating colleges in close cooperation with such technological giants as Huawei and BYD. This ensures the training of practitioners capable of working with digital ecosystems even in traditional industries, including the agricultural sector, where digital literacy and skills in managing UAVs or IoT systems are becoming a mandatory standard for modern managers [13].

The US experience in the formation of human capital is based on the creation of a unique ecosystem where academic knowledge is instantly converted into commercial innovations. The main emphasis is not only on state support, but also on the close integration of private capital, university science and entrepreneurial culture. American higher education is focused on flexibility and advanced training of specialists for emerging industries. Flexibility of curricula where students can combine fundamental disciplines with applied ones (for example, "Economics" and "Data Science"), which forms multidisciplinary human capital. Research universities such as MIT, Stanford and Harvard function as powerful R&D centers. Education here is integrated into real scientific research, funded by both the government (through NSF, NIH grants) and private corporations. US professional certification programs are actively developing short-term intensive courses (bootcamps) and micro-qualifications, which allows people to quickly change their profession according to the

needs of the labor market. In the US, a university is not just a place of study, but an incubator for business. Every large university has a unit that helps students and professors patent inventions and create startups based on them. Courses on the basics of business, critical thinking and risk management are often integrated into educational programs, even in the humanities. The presence of a developed network of "business angels" and venture funds allows talented graduates to receive financing at early stages, which keeps intellectual capital within the country.

The United States has been using a strategy of importing human capital for decades. Special visa programs (for example, O-1 for individuals with outstanding abilities or H-1B for highly qualified specialists) allow attracting the best minds from around the world. A large number of scholarships and grants for foreign students and researchers ensures a constant influx of new ideas and an intellectual advantage in global competition. The American model demonstrates that for the effective formation of human capital, high-quality education alone is not enough - it is necessary to create an environment where knowledge has a high market value, and the path from idea to commercial product is as short as possible.

The integration of education, science and business is a strategic foundation for countries striving for leadership in the global economy. Successful cases demonstrate that human capital is formed most effectively where knowledge has direct access to the market, and business takes an active part in creating educational standards. The experience of the United States of America in the formation of human capital is based on the creation of a unique ecosystem, where the academic environment acts not just as a relay of knowledge, but as a key driver of economic growth and innovation. The center of this model is the concept of the “university as an incubator”, where the educational process is inextricably linked with practical business and high-tech developments [17].

The foundation of success was the functioning of specialized structures - Technology Transfer Offices. These units provide scientists, teachers and students with a full cycle of support: from legal support for patents to attracting initial venture capital. Thanks to this, scientific discoveries made in university laboratories do not remain theoretical works, but are transformed into viable commercial startups as quickly as possible. Such a system radically changes the very nature of human capital, forming a new generation of specialists - scientist-entrepreneurs. They operate equally effectively with complex scientific categories and have competencies in the field of management, marketing and risk management. Of particular importance is the integration of universities into regional innovation clusters, the most famous of which is Silicon Valley. A synergy effect is created here: proximity to top educational centers provides companies with a continuous influx of highly motivated talents, and students gain access to real cases and advanced technologies even at the stage of study. The state in this system acts as a strategic partner, providing flexible legislation and grant support for basic research, which later becomes the basis for breakthrough commercial products [14].

Such integration allows the United States to maintain global leadership in strategic industries such as artificial intelligence, biotechnology, and aerospace development. The model demonstrates that the most valuable asset of modern society is not just knowledge, but the ability of human capital to adapt this knowledge to market needs, creating new jobs and stimulating technological progress. The high concentration of intellectual and financial resources around academic centers makes this process self-replicating and resistant to global economic transformations.

The German model of human capital formation is a unique example of how institutional support for applied research and deep involvement of the private sector create one of the most resilient economies in the world. The central element of this system is a strategic partnership, where education and science do not exist autonomously, but function as a service for technological and industrial development.

The basis of professional development of specialists in Germany is the dual system of education, which is radically different from traditional academic models. In this system, business becomes a full-fledged subject of the educational process, taking on part of the costs of training personnel from the moment they enroll in an educational institution. The student actually becomes an employee of the enterprise, where he spends most of his time, mastering the most modern equipment and real production cycles. This creates a win-win situation: the young specialist acquires relevant market skills and guaranteed employment, and the company receives a loyal employee whose qualifications fully meet its technical standards. An important link connecting academic science with industry is the activities of the Fraunhofer Society. This is an extensive network of research centers specializing exclusively in applied developments. The society acts as an intellectual “bridge”: private companies order the centers to solve specific technological problems, and scientists, involving talented students and postgraduates, develop innovative products and processes. Such interaction ensures a continuous

flow of “practical science” directly into industry, allowing Germany to quickly implement innovations in the fields of mechanical engineering, renewable energy and digital technologies [15].

The effectiveness of the German experience lies in creating an ecosystem where human capital is seen as a shared responsibility of the state and business. Thanks to a high proportion of practical training and an orientation to specific production needs, the country achieves one of the lowest youth unemployment rates in Europe. Such an integrated model ensures that investments in education and science are converted into real labor productivity and high competitiveness of national goods in the global market.

Israel's experience in the formation of human capital is an example of a unique national strategy where the security sector, academic science and state stimulation of venture capital form a holistic ecosystem. This model has allowed a country with practically no natural resources to become one of the world's leading centers of high technology, known as the "startup nation". A key element of the Israeli approach is the specific role of the military as the primary incubator of talent. Elite units, in particular in the field of cybersecurity and intelligence, play the role of leading technical universities. During their service, young people work with the most complex technological challenges in real-time and with high responsibility. This forms a special type of human capital - specialists who have not only deep knowledge in coding or engineering, but also possess critical thinking skills, teamwork and the ability to adapt quickly. After completing their service, these personnel become founders of innovative companies, bringing unique developments and managerial resilience to the civilian sector.

An important component of success was the state program to stimulate venture capital investments, known as Yozma. In the early 1990s, the state assumed significant financial risks, offering foreign investors attractive co-financing conditions. This allowed attracting global capital to local scientific developers. The created system ensured that talented scientists and engineers had access to resources to transform their ideas into global products. State support, combined with private investment, created an environment where innovation becomes the basis of exports and economic growth.

Today, the integration of education, the army and business in Israel provides the world's highest concentration of scientists and engineers per capita. The state continues to invest in research centers at universities that work closely with transnational corporations. This model demonstrates that the effective formation of human capital in the modern world requires not only high-quality education, but also the creation of "elevators" that allow talents to quickly go from specialized training to creating their own high-tech business that competes on a global scale.

Finland’s experience in human capital development is an example of extraordinary adaptability and the ability to rapidly transform the national economy through intellectual resources. The Finnish approach is based on the creation of open innovation ecosystems and the introduction of the concept of lifelong learning as the foundation of public welfare. One of the most striking examples of such integration is the experience of the city of Oulu, which has become a global technology hub. The success of this location was made possible by close interaction between the university, research centers and business. The uniqueness of the Oulu model lies in the physical and mental unification of the participants in the process: students, researchers and developers from private companies work in common spaces. Such an ecosystem promotes the instant exchange of ideas, where academic research is immediately tested for market viability. Even after serious structural changes in large corporations such as Nokia, this region was able not only to preserve human capital, but also to diversify it, creating hundreds of new startups based on the accumulated competencies.

A key factor in Finland’s sustainability is the state policy of “lifelong learning”. The Finnish education system is designed so that a person at any age can easily change professions or improve their qualifications without losing their social status. When certain industries lose their relevance, the state, together with new technological clusters, launches large-scale retraining programs. This allows workers to quickly move from traditional sectors to the digital economy, energy or creative industries. Educational programs are developed in partnership with business, which ensures that knowledge meets real market needs.

Thanks to radical openness and an emphasis on adaptability, Finland is forming human capital ready for the challenges of an unstable and unpredictable world. The state invests not just in diplomas, but in the ability of citizens to constantly update their own competencies. This strategy allows the country to maintain leadership in human development and innovation activity indices, demonstrating that the main advantage in a modern economy is the ability to learn faster than competitors.

Analysis of the experience of the world's leading countries allows us to conclude that effective formation of human capital in modern conditions is possible only with deep integration of education, science and the real sector of the economy. Each of the countries under consideration is building a unique ecosystem where knowledge has

direct access to the market, and business acts as an active customer and co-author of training programs. Germany demonstrates success through a dual system of training and applied science clusters that provide industry with ready-made specialists. Denmark focuses on the concept of "Flexicurity" and "green" energy, creating conditions for a painless change of profession throughout life. China is implementing a large-scale state strategy of investments in STEM disciplines and digitalization, striving for global technological leadership. The United States focuses on the "university-incubator" model, where scientific discoveries are instantly converted into commercial startups and venture projects. Israel effectively uses military experience as an incubator for high-tech talents, which later form the basis of a “startup nation”. Finland relies on the radical openness of innovation ecosystems and the ability of a person to continuously update their competencies. Common to all leaders is the understanding of human capital as the main asset of national security and economic resilience to crises. Thus, modern education is transformed from a process of relaying knowledge into a flexible mechanism for human adaptation to the requirements of a high-tech and changing world.

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