

Sustainable development of human capital while solving global problems of green technologies

Aliyev Shafa Tiflis^{1,2,3,} Salamova Ayna⁴ Alieva Marina⁵*

¹ Sumgait State University, Sumgait, Azerbaijan

² Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan

³ Western Caspian University, Baku, Azerbaijan

⁴ Kadyrov Chechen State University, Grozny, Russia

⁵ Dagestan State University, Khasavyurt, Russia

Abstract. The ultimate reduction in carbon dioxide levels in the atmosphere can only be achieved through the large-scale implementation of green technologies and the effective use of human capital. This article examines the role of human capital in the development of green technologies and its impact on achieving environmental sustainability. The study draws attention to the relationship between education, skills and innovation required to develop and implement green technologies. The authors highlight the importance of investing in education, training and research to develop human capital capable of driving innovation in environmentally sustainable technologies. It also examines the policy and practical measures needed to support green technologies and their diffusion across various sectors of the economy. In conclusion, the article highlights key areas for future research and highlights the importance of collaboration between the public and private sectors to achieve the common goal of environmental sustainability.

1 Introduction

Schultz's human capital theory and Romer's endogenous growth theory both underscore the crucial role of human capital in promoting technological progress and fostering economic output. In the contemporary landscape of Industry 4.0, human capital emerges as a pivotal

* Corresponding author: salamova_chgu@mail.ru

driver of organizational innovation. While education and health are recognized as primary components of human capital, previous research has often overlooked the latter when examining its relationship with innovation, primarily equating human capital with education alone. Classical economic theories advocate for stringent environmental policies to address negative externalities associated with pollution.

In contrast to conventional approaches to analyzing socio-economic systems, which focus on determining the state of local components and presenting a generalized outcome, the proposed method advocates for transitioning from a global to a micro-level examination of human capital development.

2 Research methodology

The methodological assessment of human capital sustainable development is framed within the context of universal research at global, macro, and micro levels, considering socio-economic and environmental aspects in line with the principles of self-organization processes in synergetics. This assessment unfolds sequentially:

- At the global level, the general state of human capital reproduction systems is evaluated by assessing their potential for digitalization.
- At the macro level, the overall environmental friendliness of natural and man-made systems is characterized based on systems analysis results.
- At the micro level, specific factors and processes affecting ecosystem stability are analyzed to assess the risk of hindering sustainable human capital development.

At the macro and micro levels, changes in human capital reproduction elements and factors are examined to identify instances of system destabilization and stabilization processes. This systematic analysis enables the identification of factors requiring mitigation and the activation of stabilization mechanisms, particularly in the digital economy context.

3 Results and Discussions

Human capital encompasses a range of attributes including health, education, intelligence, skills, and values, all of which contribute to workforce quality and economic value. Of these, health and education are particularly crucial. Educational human capital, enriched with knowledge, technology, and green innovation experience, plays a vital role in driving green technology innovation. Firstly, a well-educated workforce fosters environmental awareness and cultivates talents proficient in green technology innovation within enterprises. Secondly, higher levels of educational human capital correlate with greater income and environmental consciousness among consumers, influencing low-carbon consumption patterns and encouraging environmentally friendly choices. Moreover, individuals with high educational human capital are more likely to initiate environmental organizations, advocating for reduced resource wastage. Thirdly, educational human capital facilitates knowledge spillovers, promoting the adoption of advanced technologies and stimulating local green innovation efforts. Healthy human capital plays a distinct role in driving green technology innovation, contrasting with the effects of educational human capital. Firstly, by furnishing workers with robust physical and mental energy, healthy human capital enhances labor efficiency.

Governments often employ environmental regulations to compel enterprises to alter production processes, products, and technologies, thereby reducing pollutant emissions. Stricter regulations lead to higher pollution control costs, prompting increased R&D

expenditure by enterprises to maintain profitability and promote green transformation. Conversely, some scholars contend that environmental regulations hinder green technology innovation due to a "compliance cost" effect. Under stringent regulations, enterprises allocate limited funds to pollution prevention, crowding out investment in green technology innovation. Additionally, there is evidence suggesting a non-linear relationship between environmental regulations and green technology innovation. Some posit an inverted U-shaped relationship, where innovation initially increases with regulatory intensity but declines after a threshold is reached. From a dynamic perspective, certain studies demonstrate short-term inhibitory effects but long-term positive impacts on productivity growth. Environmental regulations are further categorized into command-and-control, market-incentivized, and public voluntary types, each influencing innovation differently. Command-and-control regulations impose economic and administrative penalties, incentivizing innovation, while market-incentivized regulations spur technological upgrades by increasing environmental costs. Public voluntary regulations rely on public awareness, albeit with limited efficacy, in fostering innovation.

Human capital, similar to other forms of capital, exhibits specific characteristics: it can change in value and depreciate economically, it is inseparable from individuals, its reproduction requires investments in social spheres and infrastructure, and it multiplies through the acquisition of experience and skill improvement.

The multi-criteria assessment identifies negative impacts on the human capital reproduction ecosystem across three components: environmental, economic, and social. At the macro level, the methodology for assessing human capital development sustainability involves identifying regions with high-risk levels based on environmental conditions and priority problems affecting quality of life. This allows for effective risk mitigation strategies and the preservation of ecosystem functionality.

The ecological risk (E) at the macro level is determined by the probability of sustainability disruption within the human capital reproduction ecosystem components. The ecological risk ER of a specific component is estimated based on probabilistic characteristics of the discrepancy.

Safety management principles involve allocating resources efficiently to reduce various risks while ensuring a predetermined level of ecosystem quality. This level is defined by economic, social, and technological standards and capabilities.

Given the stochastic nature of system transitions, micro-level analysis is conducted to examine technological and economic aspects of organizations' activities aimed at mitigating human capital reproduction dysfunctions. Decision-making involves regulating the situation to restore environmental subsystem stability within acceptable risk levels.

A systems analysis of multifactorial risks for ecosystem components is conducted, specifying factors affecting specific objects and conditions. Each risk factor is characterized by an indicator of anthropogenic load, which determines the level of disturbance in ecosystem stability and the associated risks to human capital development.

4 Conclusions

The theory of institutional regulation underscores the influence of economic and social regulations on organizational behavior. Enterprises navigating pollution emission and green technology innovation inevitably contend with environmental regulatory policies. As elucidated above, human capital significantly impacts enterprise-level green technology

innovation, with environmental regulations exerting a moderating influence on this dynamic.

Formal environmental regulations can reshape capital allocation within industries, fostering green total factor productivity improvement by reducing the relative reliance on physical capital and mitigating capital-factor mismatches. However, stringent command-and-control regulations may prompt enterprises to prioritize short-term pollution prevention and control investments over human capital development, thereby dampening the positive impact of human capital on green technology innovation.

Human capital reproduction ecosystem sustainability entails ensuring homeostasis within its subsystems while meeting safety requirements across economic, ecological, and social indicators. This involves maximizing production efficiency within the digitalization framework for economic stability, maintaining optimal levels of biological productivity for ecological balance, and prioritizing public health for social well-being.

In the context of digitalization, the conceptual model for human capital sustainable development enables the assessment of quality regulation across socio-economic and environmental dimensions in accordance with safety management principles. This includes considering the acceptable risk concept to balance the benefits of development with potential hazards.

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