

# Human capital in the circular economy: how to turn waste into innovation

Anastasiya Ilyina<sup>1</sup>

<sup>1</sup> Department of Public Administration, State University of Trade and Economics, Kyiv, Ukraine

Corresponding author E-mail: [a.ilyina@ujis.in.ua](mailto:a.ilyina@ujis.in.ua)

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## Abstract

The relevance of the topic is due to the transition of the world economy from a linear production-consumption-waste model to a circular one, where human capital plays a key role as a driver of innovation and sustainable development. It is the knowledge, creativity and environmental awareness of employees that determine the ability of businesses to turn waste into resources and create added value. In the context of global environmental challenges, investing in human capital development is becoming a strategic tool for the transition to a green economy. The purpose of the article is to substantiate the role of human capital in the development of the circular economy. The study uses such methods as analysis and synthesis, system analysis, qualitative content analysis, case analysis, comparative analysis, institutional analysis, and conceptual analysis. The object of research is the circular economy as a modern model of sustainable development. The article highlights the role of human capital as a key mechanism for the transition to a circular economy. The directions of integration of the circular economy principles into the development of human capital are determined. The influence of each level on the formation of new competencies is determined. As a result, a modern paradigm of human capital is being formed. The main ideas and trends in modern research and practice related to waste management and human capital management are analyzed. A comparison of classical and green investment approaches (ESG/impact) shows a shift in planning horizons, evaluation criteria, and the importance of human capital. In practical terms, this can serve as a basis for developing effective mechanisms for training, retraining, and motivating staff to apply the principles of the circular economy at enterprises. Involvement of human resources allows us to optimize production processes, reduce waste and increase resource efficiency. The results obtained can serve as a basis for the formation of educational programs, corporate strategies in the field of sustainable development and state policy on the "green" transformation of the economy.

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## 1. Introduction

The world in which people live produces tons of both physical and intellectual waste, leaving behind mountains of garbage: from plastic bags to unrealized ideas and projects. However, this waste has unique potential. The circular economy is built on the principle of minimizing waste and maximizing reuse of resources. What was considered unnecessary yesterday can become the raw material for new economic value today.

Nowadays, a common challenge for the human community is to recycle not only household waste, but also intellectual and social waste. This challenge requires the formation of new professions, the use of advanced technologies, and the transformation of social culture, in which personal mistakes and failures can become lessons for others and a source of value that allows this experience to be transformed into innovations.

### 1.1. Literature review

To date, many scholars have studied the problems of the circular economy and the role of human capital in innovation. However, there is still lack of research focused on the very foundations of sustainable development related to the context in which the circular economy gains its importance.

Bichisao et al. [1] in their work "Horizon 2030 " characterized the challenges and opportunities of the European Union until 2030 in terms of finance, migration, technology and environment. However, the scenario analysis has not been sufficiently translated into concrete tools and indicators of progress. Castro-Lopez et al. [2] showed that entrepreneurial orientation stimulates "circular human resource management" and innovation. At the same time, the new CHRM metric still needs to be validated in different sectors and countries. Cheng et al. [3] empirically linked green logistics and green human capital to the circular economy through the mediating role of sustainable production. Nevertheless, longitudinal studies outside of Bangladesh's garment industry are lacking. Ly [4] conceptually linked green HRM practices and inclusive leadership to circular economy outcomes. However, field trials in different countries and quantitative assessments of the impact of leadership are lacking. Marrucci et al. [5] demonstrated the contribution of green HRM to the circular economy and the environmental/operational performance of certified organizations. However, research on causal mechanisms and external validity beyond ISO-certified companies remains relevant. Masruchiyah et al. [6] investigated how green human capital and the circular economy strengthen the resilience of cities to water resources. However, empirical evidence on the applicability of these findings is limited. Panchenko et al. [7] studied the importance of investment strategy in the strategic management of service companies. However, the indicators that reflect the impact of investment portfolios on sustainable development in the context of the circular economy are not sufficiently studied. Prodius et al. [8] studied international corporate strategies and entrepreneurial paradigms in the context of global integration. The study should combine strategic typologies with indicators of the circular economy and decarbonization. Macedon et al. [9] proposed a conceptual integration of artificial intelligence and human resource management as additional drivers of the circular economy. However, field experiments to test the impact of artificial intelligence on circularity and employment are still lacking.

Taken together, this suggests that the link between the circular economy and human capital requires further research at the firm, industry, regional, and country levels, where human shortcomings and previous design errors, as well as losses generated during project implementation, become driving forces for studying the factors shaping innovation.

## 2. Methods

The study uses a set of methods that provide an interdisciplinary analysis of the problem:

- 1) analysis and synthesis – generalization of existing approaches to the circular economy, innovation-oriented development and the role of human capital;
- 2) system analysis – studying waste as an element of the socio-economic system and identifying the interrelationships between technological, environmental and human factors;
- 3) qualitative content analysis – identifying key ideas and trends in current research and practices related to waste management and human capital management;

- 4) case analysis method – study of successful examples of circular economy implementation and the role of human capital in their implementation;
- 5) comparative analysis – comparison of investment models in the traditional economy and green technologies with a focus on the prospects for financing innovations in the waste management sector;
- 6) institutional analysis – assessment of the impact of state and international institutions on the formation of the investment environment and the development of new professions in the circular economy;
- 7) conceptual analysis – understanding the category of “waste” not only in material terms, but also in intellectual and social dimensions, as well as interpreting innovations as a form of transforming mistakes and failures into value.

### 3. Results

The circular economy is a practical tool for implementing sustainable development. If sustainable development is a strategy, then the circular economy is a mechanism for achieving it [4].

The circular economy is a model opposed to the linear economy, where all waste or any unnecessary or used items are thrown away, destroyed, and recycled. In this context, the focus is on minimizing waste, treating it not as an end product but as a resource for a new production cycle. This approach allows for the maximum reuse of resources, where materials are designed for durability, repair, and recycling. This is where eco-design plays a particularly crucial role. Eco-design refers to the initial design of products with a view to their future reuse or recycling, aimed at creating closed cycles, i.e. closing supply chains where the by-product of one industry becomes the raw material for another.

In addition, the circular economy contributes to reducing environmental pressure by limiting excessive resource extraction and waste generation. It also promotes long-term economic resilience through more efficient production and consumption patterns. Furthermore, the implementation of circular economy principles encourages innovation and the development of environmentally friendly technologies.

The theoretical basis of the circular economy is based on the following concepts:

- industrial ecology, where waste from one process serves as a resource for another;
- "cradle to cradle" - an approach where products are designed in such a way that after use they become raw materials, not waste;
- the concept of product durability – the priority of extending the life cycle of a product through repair and modernization [3].

The circular economy is based on sustainable development as a global paradigm enshrined in UN documents. Its basic principles are related to the triad of environmental, economic, and social sustainability, where nature conservation and reduction of pressure on ecosystems are directly linked to growth through the rational use of resources [10]. This significantly affects the efficiency of resource use (the transition from the extensive consumption of resources to their rational use) and, as a result, equity (meeting the needs of the present without compromising the ability of future generations to meet their own needs), which, in turn, becomes a factor in the development of human capital [11]. The dynamics of the global economy circularity in 2019–2024 is shown in Figure 1.

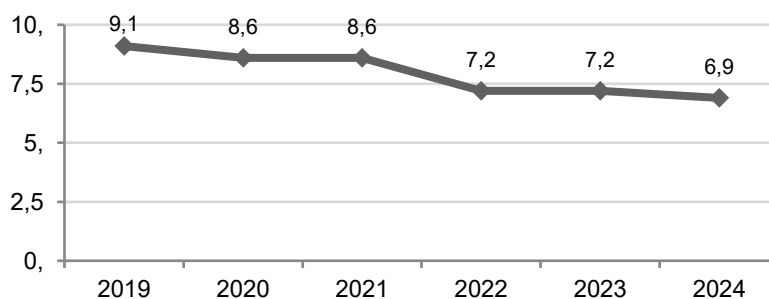


Figure 1. The level of circularity of the world economy in 2019–2024  
Source: created by the author based on the circularity GAP report [12]

There is a downward trend in the share of resource reuse. Such dynamics indicate that the implementation of circularity principles is constrained not only by technological or financial barriers, but also by the lack of competent professionals capable of generating innovative solutions in the field of waste and resource management. That is why the development of human capital regarding education, skills, and environmental culture is becoming a key condition for the transition from declarations to the actual implementation of a circular economy model.

The waste management and recycling sector employs approximately 6.9 million people globally, which is about 0.2% of total global employment [13].

A skills shortage in the recycling industry is present where more than 60% of workers feel the need for upskilling due to new technologies [14]. Figure 2 shows the dynamics of employment in the waste management and recycling industry in the world.

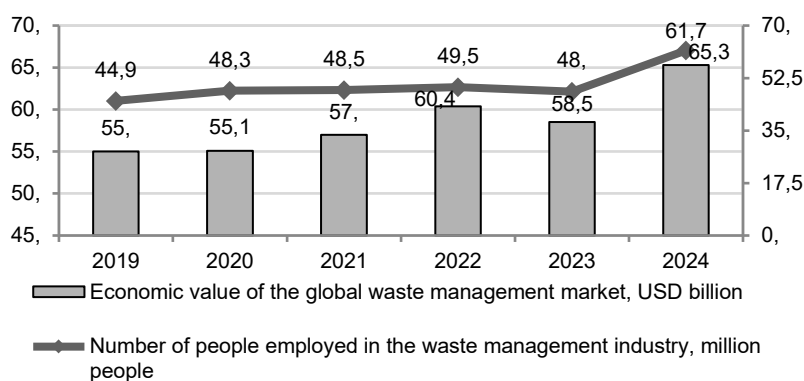


Figure 2. Dynamics of the economic value of the global waste management market and employment in the waste management and recycling industry in the world for 2019–2024

Source: built by the author based on [15], [16]

As can be seen from Figure 2, the global waste recycling market has grown with relatively stable employment in industry. This indicates technological innovation and growing demand for recyclable materials, and at the same time, it emphasizes the critical role of effective human capital engagement in the transition to a circular economy.

In the circular economy, human capital is understood as a combination of knowledge, skills, competencies and values that ensure the effective implementation and maintenance of circular economy principles. It includes:

- professional competencies: engineering, environmental, managerial, and financial;
- innovative competencies: creativity, entrepreneurial thinking, critical analysis and willingness to experiment;
- social competencies: ethics, environmental responsibility, ability to cooperate and solve problems collectively [6].

For deepening the comparative component of the research, it is expedient to compare the trajectories of development of circular economies in countries with different income levels, institutional capacity, and technological base. Such an approach gives the opportunity to discover not only differences in the pace of transition, but also differences in the structure of drivers. The comparison of high-income and developing countries shows the impact of access to capital, quality of regulation, and human resources potential on the results of circular transformations.

It is advisable to use the paired comparison method. For example, the Netherlands and Ukraine demonstrate different starting conditions. The first country has formed secondary steel markets and raw materials, developed logistics for the return of products, and innovation clusters. Ukraine has strong industrial and agricultural resource potential but still faces infrastructure restrictions and a deficit of investment. The other pair, Germany

and Indonesia, shows a difference between a technologically mature model and a model of fast catching-up development. In Germany high standards of sorting, advanced producer responsibility, and demand for environmentally friendly goods dominate. In Indonesia the dynamics are forming through urbanization, pressure from plastic waste, and the need to create jobs (page 1).

Table 1. Comparison trajectories development circular economy

No	A couple of countries	Level development	Leading drivers	Basic barriers	Priority for the human capital
1	Netherlands–Ukraine	High/medium	Innovation, logistics/resource base	Cost energy/infrastructure	Engineers, managers recycling
2	Germany–Indonesia	High/medium	Regulation/urbanization	High standards/weak gathering waste	Technical preparation personnel
3	Sweden–Kenya	High/low average	ESG-investments/social initiatives	Market saturation/shortage financing	Professional teaching
4	Japan–Vietnam	High/medium	Technology/industrial growth	Aging population/environmental pressure	Digital and production skills

Source: built by the author based on [11], [16]

Such comparison expedient integrates into the article through system indicators: share recycling waste, resource productivity, employment in circular economy sectors, volume green investment, level ecological competencies employees. Human capital is a key resource for the transition to a circular economy. Educational capital is accumulated through the training of specialists. Further, this educational capital is transformed into innovation capital. In this context, human capital is the integration of knowledge, skills, and values. They contribute to the transition from a linear economy to a sustainable development model, where waste is transformed into resources and mistakes into innovative opportunities [5]. Practical recommendations for integrating the principles of the circular economy into human capital development at the state, corporate, and educational levels are summarized in Table 2.

Table 2. Directions for integrating circular economy principles into human capital development

Level of implementation	Recommended measures	Expected effect on human capital	Tools
Educational	Include courses on sustainable development, waste management and green technologies in educational programs.	Training specialists with new competencies in the field of circular economy.	Courses on circular economy, internships at waste recycling companies
Corporate	Setting ESG standards and incorporating them into employee KPIs. Training staff in the principles of the circular economy.	Development of employee competencies. Creating an innovation-oriented corporate culture.	Training sessions, internal hackathons and innovation labs, ESG system, corporate incentive programs
Governmental/political	Tax incentives and financial support for companies. Support for startups.	Developing incentives for training highly qualified personnel; community engagement	National competence centers, grants, public-private partnerships, regulatory incentives
Socio-cultural/public	Developing social and cultural initiatives, media campaigns, and art projects to promote the ideas of zero waste and waste = resource. Involvement of local communities in recycling and reuse projects.	Development of social values. Raising environmental awareness. Involving communities in innovation processes.	Media campaigns, eco-festivals, public workshops, art projects on the topic

Source: developed by the author

Implementing these principles will help create an innovation ecosystem in which people, technology, and resources interact for sustainable development.

Integrating the circular economy into human capital development requires a systematic approach:

- education ensures the flow of specialists with new competencies;
- corporate strategies consider sustainable development at the level of business models;
- public policy creates incentives and institutional support;
- cultural initiatives create a new social perception of waste and innovation.

Figure 3 demonstrates the impact of each level on the formation of new competencies, social responsibility, and active participation of people in the creation and recycling of values. These coordinated efforts strengthen the interaction between education, business, and policy, ensuring the effective implementation of circular economy principles.

Such an integrated approach enhances systemic coherence and accelerates the formation of a sustainable innovation-driven economy. As a result, a modern paradigm of human capital is being formed, where people are transformed from passive consumers of resources to active participants in sustainable development.

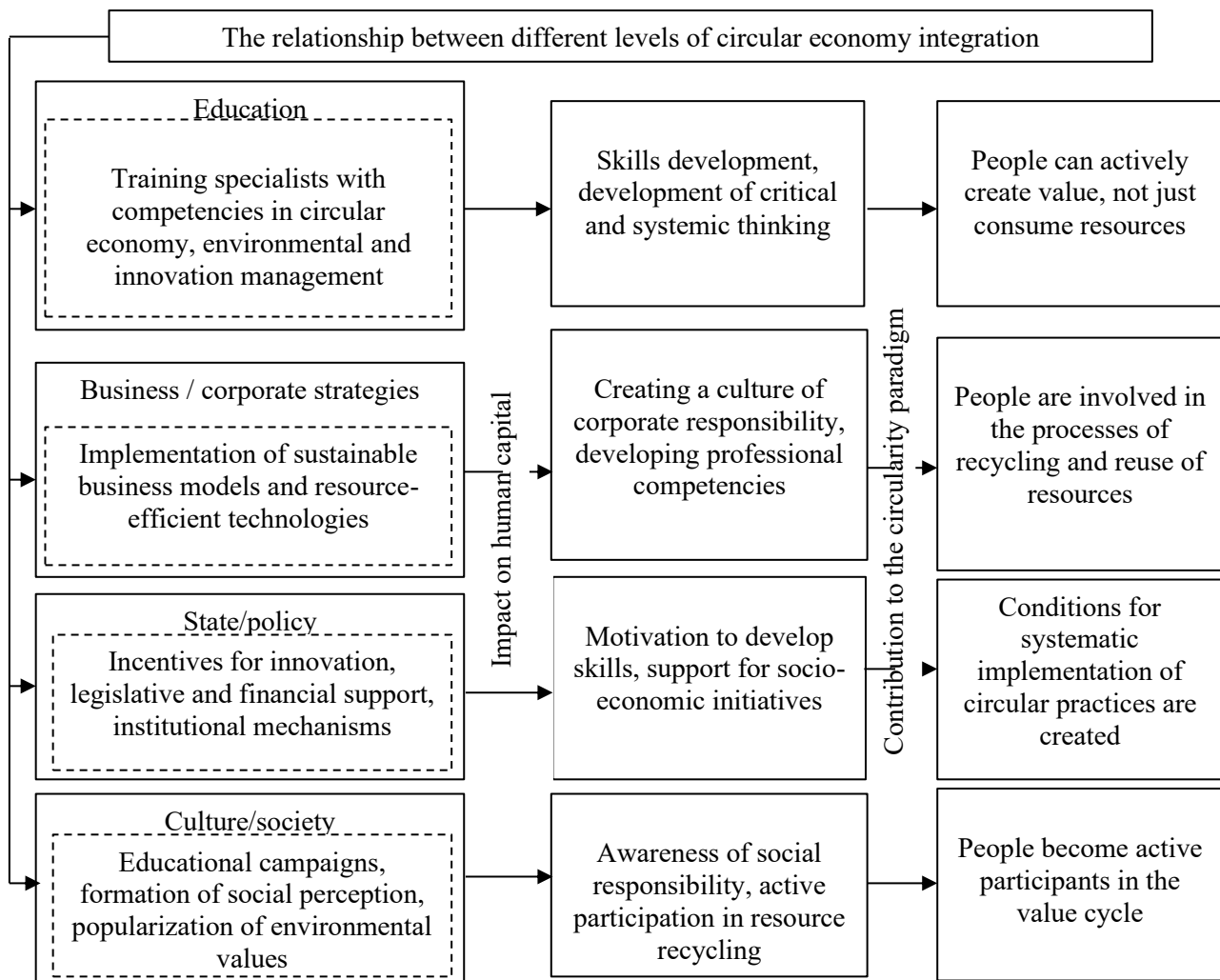


Figure 3. Formation of a new paradigm of human capital

The above-mentioned social and cultural aspects shape not only environmental behavior, but also an innovative mentality. When people perceive waste as a resource and mistakes as lessons, a new culture is formed:

- responsible consumption that helps reduce waste;
- innovative entrepreneurship, where startups use the experience of failure as part of the development cycle;
- social integration by involving vulnerable groups in recycling projects.

Practical recommendations for small and medium-sized enterprises should be based on a phased change in the operating model. First of all, it is advisable for managers to conduct an audit of material flows, energy consumption and waste structure. Such analysis reveals resource losses and areas of overspending. After that, the enterprise should review its purchasing policy, focusing on secondary raw materials, repairable materials and local suppliers.

At the same time, it is necessary to invest in human capital. Staff should be trained in resource sorting, lean manufacturing, digital inventory control and environmental management methods. It is advisable for production teams to introduce internal programs for submitting rationalization proposals. This activates applied innovations and reduces operating costs.

Small firms should form partnerships with processors, logistics operators, and educational institutions in the region. Joint projects reduce infrastructure costs and accelerate the exchange of expertise. Special attention should be paid to transparent non-financial reporting. Data on waste reduction, material reuse, and employee training increase the trust of customers, banks, and investors.

#### 4. Discussion

Modern waste recycling practices demonstrate a shift from the linear logic of "production-consumption-disposal" to an innovative model where each type of waste is considered a resource. These practices are the intersection point between technology, investment, and human capital.

For example, municipal solid waste (MSW) recycling may include plastic recycling. Such conditions facilitate the introduction of the concept of "smart containers" and digital monitoring systems for waste sorting. In this context, the concept of "design for disassembly" is applied, focusing on the production of innovative products from waste [9]. All these practices can be applied in social and entrepreneurial initiatives related to zero waste projects, local business models, social recycling programs (providing jobs for vulnerable groups), and circular economy startups focused on innovative investments (Table 3).

Table 3. Successful cases of circular economy implementation: the relationship between investment and human capital

Demonstrate	Year of launch	Investment year	Investor/partner	Amount of investment	Human resources	Activities
Interface – Net-Works	2012	2012	G&A	< USD 1 million at the beginning, USD 23.5 million at the end	Designers, engineers, field teams	Eco-design, public collection
Loop industries	2010	2021	SKGC	56.5 million USD	Scientists and business leaders	Scaling up recycling technology into an industrial project
TerraCycle– the Loop	2001	2020	Series A Reg A+	25 million USD 19.5 million USD	Marketing team	Management of the reuse platform
Renewcell (Circulose )	2012	2019/ 2021	Series A loan	5 million dollars 30.75 million euros	Researchers + investors	Industrial scale deployment
Ecopost (Kenya)	2009	2023	Borealis grant	-	Social entrepreneurs	Involvement of women and youth

Source: developed by the author

As it can be seen, Interface–Net-Works is an early (first wave) example of an inclusive circular model. In 2012, Interface, together with ZSL, launched a program in the Philippines that included the collection of discarded fishing nets, yarn, and carpet tiles. This demonstrates both the experience gained over more than a decade and the high replicability of the model. The initial investment was less than \$1 million, with a significant multiplier effect. The Oxford SBS case study notes that a relatively small initial investment generated a multiple commercial effect (tens of millions in turnover). This suggests that the model is “light” on capital but strong on organizational design and community engagement, a rare example of a high return on investment in human capital. Each stakeholder plays a role in transforming the old and undesirable into the new and useful [17]. For example, product designers and engineers are responsible for eco-design for recycling, while field teams are working with fishing communities to handle logistics, motivation, and set quality standards for raw materials [18].

The profile of Loop Industries (Canada, headquartered in Quebec) dates to 2010. In 2021, SK Global Chemical invested \$56.5 million, after which the joint Infinite Loop™ program was announced in Ulsan with plans to build up to four plants by 2030. This indicates a “proven” scale, reflecting the transition from research and development to industrialization. Here, the strategic equity format (a 10% stake at \$12 per share) serves as an indicator of the confidence of a major chemical player in PET depolymerization technology [19]. The collaboration between research chemists, operations managers and corporate developers at the partner company (SK) is an example of how innovation is transferred from the lab to industry through an alliance [20].

TerraCycle was founded in 2001 in Trenton, New Jersey (USA), and has gone through a long journey of raising capital. In the early stages, the company relied on microfinance (USD 2000) and competitive grants, later moving on to venture capital offers and subsequent rounds of financing. In total, according to industry databases, the company raised tens of millions over several rounds, which is a typical ladder growth trajectory for impact businesses. In terms of investment structure, this means a “composite” model rather than relying on one big check [21]. For TerraCycle, the focus was not so much on one-time large capital injections as on a portfolio-based partnership model where brands, municipalities, and consumers co-invest in infrastructure, logistics, and demand. This explains the international scale of the project, despite the relatively modest capital intensity of its core operations. It is a model that requires intensive human resources management, through which the company changes habits (collecting the “non-recyclable”), not just processes [22].

Renewcell (Circulose) was founded in 2012 in Sweden (Stockholm). In this case, the credit line of up to EUR 30.75 million for the first commercial plant in Sundsvall reflects the transition from pilot to industrial scale (60,000 tons per year). This is a sign of both technological maturity and a European political and financial mandate [23]. The Horizon 2030 program is a debt-risk capital program aimed at reducing financial barriers for capital-intensive green industries, presented as a public-private model of risk reduction for investors [1]. This model illustrates ecosystem capital as the ability to integrate materials into existing chains (design/procurement) through partnerships with fashion brands (H&M and others), while drawing on the engineering expertise of scientists, operators, and brand curators. In this case, a closed textile cycle becomes possible with the support of shipment agreements with brands and sustainable financing of both capital expenditures and working capital. At the same time, a lack of human resources is evident in cellulose-related technologies and in industrial sourcing of raw materials [24]. This illustrates that scaling circular economy technologies depends not only on financial instruments but also on the availability of specialized technical and managerial competencies. Human capital therefore becomes a limiting factor in the transition from pilot projects to full industrial deployment.

The social enterprise Ecopost was launched in 2009, and in 2023, the Borealis social fund announced funding to expand plastic collection and recycling in Kenya. In this case, the model has been proven by a global player in the field of raw materials, which opens the way to scaling. The amount of investment is undisclosed (CSR/impact finance), which is typical for corporate social/impact instruments that aim to strengthen operational capacity (equipment, logistics, formalization of collectors) rather than equity. This reduces the risks

of raising funds for local businesses [25]. This case demonstrates the management of social projects that actively involve young people in solving the “dual” task of recycling as a means of providing employment [26].

The traditional investment model is primarily focused on short-term profit and risk minimization, while green investments consider not only financial returns but also environmental and social sustainability, as well as long-term value creation. Comparing these models helps to identify the incentives and barriers that shape the development of the circular economy, as well as how human capital can be integrated into investment decisions (Table 4). This distinction is crucial for understanding how different investment logics influence both the pace and the quality of circular economy transformation, particularly in terms of how effectively human capital, innovation, and sustainability goals are integrated into long-term development strategies.

Table 4. Comparison of investment model indicators: traditional and green investments

<b>Indicator</b>	<b>Traditional investments</b>	<b>Green investments (ESG, impact, circular economy)</b>
Main goal	Maximize profits, fast return on investment	Profit plus environmental and social sustainability
Planning horizon	1-5 years	5-20 years and more
Evaluation criteria	Financial indicators: profitability, risk, liquidity	Triple bottom line: profit, planet, people
Investment sectors	Oil, gas, metals, real estate	Renewable energy, waste management, cyclical startups
Financial instruments	Loans, IPOs, bonds	Green bonds, ESG funds, grants, crowdfunding
The role of human capital	Capital and risk management	Key factors: environmental specialists, engineers, entrepreneurs, communities
Risks	Market fluctuations, inflation, political instability	Technological (immaturity), institutional (regulation); lower reputational risks
Examples	IPOs of oil and gas companies; metallurgical bonds	Renewcell – EUR 30.75 million EIB loan [23]; Loop Industries – USD 56.5 million from SKGC [20]; Ecopost – Borealis grant [25]: amount undisclosed, focus on social impact

Source: developed by the author

Comparing traditional investments with green investments, the traditional ones seek quick returns and minimize risks. On the other hand, green investments involve a long-term horizon, as environmental projects take time to pay off. When evaluating projects, the traditional model prioritizes return on investment, while green investment relies on the concept of the triple bottom line, which includes profit, planet, and people [7].

Human capital is shifting from resource-based industries to renewable energy, waste management, and clean technology projects, where new financial instruments such as green bonds, grants, and crowdfunding are being used. In the traditional model, human capital plays a narrowly financial role, while in the green model it is central – environmentalists, engineers, entrepreneurs and even local communities become the driving forces behind projects [8]. Examples include:

- Renewcell (Sweden) – in 2021, the European Investment Bank invested €30.75 million in a loan to launch industrial production of recycled textiles [23];
- Loop Industries (Canada) – in 2021, SK Global Chemical invested USD 56.5 million as a strategic investment to implement Infinite Loop™ technology [19];
- Ecopost (Kenya) – in 2023, the Borealis Social Foundation provided grant support (amount not disclosed) to expand plastic recycling and engage women and youth, which is an example aimed at achieving a positive result [25].

A comparison of traditional and green investment models shows that green investment unlocks the potential of human capital by engaging engineers, entrepreneurs, and communities in the process of turning waste into value.

The circular economy is not only a technological and financial model, but also a cultural shift. The way society perceives waste, mistakes, and failures determines the speed and depth of transformation. In traditional culture, waste is perceived as the end of a life cycle, and a mistake is seen as a failure. In the circular economy paradigm, waste is a resource, and a mistake is an opportunity for innovation.

Thus, the Zero waste initiative is becoming a social phenomenon by reducing waste through the refusal of single-use items, as well as reusing and recycling. This has a significant impact on the public consciousness, as consumers begin to feel responsible for their own waste [27].

In terms of education and upbringing, schools and universities are introducing sustainability and circular design programs aimed at fostering a culture of recycling from childhood. This includes waste sorting, developing green habits, and participating in environmental projects [28].

As a result, the integration of the circular economy into human capital development will lead to a new paradigm of human capital in which people are able to actively create value by understanding waste as a resource in material and intellectual dimensions.

## 5. Conclusions

Sustainable development and the circular economy are impossible without the transformation of human capital. The future of innovation is determined not only by investments in new technologies, but also by the extent to which people are willing to rethink their knowledge, skills, and values.

Modern recycling practices cover a wide range of waste: from household and organic to electronic and textile, creating new products and industries. Successful cases, including Interface, Loop Industries, TerraCycle, Renewcell, Ecopost have demonstrated that human capital has been a critical factor during their implementation, including design and community engagement, research, social entrepreneurship, and cultural initiatives.

A comparative analysis of investment models revealed a difference between traditional and green investments, with the latter relying on a long-term horizon, a triple bottom line (“profit-people-planet”), and the strategic role of human capital. Here, the socio-cultural perception of waste and mistakes as resources radically transforms the approach to innovation: it moves from “rejection and failure” to “experience and a new cycle.” In this context, it is necessary to integrate the principles of the circular economy into education, corporate strategies, public policy, and the cultural development of society.

Future research perspectives may include further development of tools for assessing the contribution of human capital to circular economy projects, studying the effectiveness of educational and cultural initiatives that promote circular thinking, and analyzing new investment mechanisms (ESG bonds, impact funds, crowdfunding) and their role in promoting waste-based innovation.

### Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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