

CRITICAL ASPECTS OF DIGITALIZATION OF THE CIRCULAR ECONOMY

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Abstract: The digital circular economy is considered the sustainable solution in terms of resource use. However, a comprehensive analysis reveals that the integration of digital technologies into circular models also generates a series of unintended consequences.

This article analyzes the possible negative implications of digitalization in the circular economy, in particular the impact on the environment, the labor market, economic competitiveness and the regulatory framework. It also proposes public policy measures aimed at ensuring an orderly, sustainable and inclusive transition.

Keywords: circular economy, digitalization, sustainability, socio-economic impact, public policies

Introduction

The adoption of digital technologies within circular economy models offers considerable potential for optimizing resource consumption, improving the ability to monitor material flows and facilitating the reuse of products through better management of their life cycle. Through tools such as artificial intelligence, blockchain or the Internet of Things (IoT), increased traceability of components and raw materials can be ensured, which directly contributes to the transparency of supply chains and the accountability of economic actors.

However, as digitalization becomes an integral part of essential infrastructure, with a wide applicability, from automated logistics networks to interconnected industrial processes, systemic risks also emerge, such as: cyber vulnerabilities associated with the collection and processing of sensitive data, difficulties in defining and protecting intellectual property rights generated by digital collaborations, as well as the potential to amplify socio-economic disparities, especially in regions or communities with limited access to digital infrastructure.

Thus, digital transformation in the context of the circular economy is not an easy process, free from contradictions. Beyond the obvious benefits related to efficiency and sustainability, there is the issue of equity of access, data sovereignty and distribution of the economic value generated. An analytical framework capable of integrating these multiple dimensions: technological, economic, social and legal, is therefore necessary in order to have a coherent and correct vision of the transition to a digital circular economy.

This study aims to explore these interdependent aspects, providing a critical analysis of how digitalization can support or, on the contrary, undermine sustainability objectives. By adopting a transdisciplinary perspective, it aims to understand the emerging challenges and formulate strategic directions for the responsible integration of digital technologies into the architecture of an inclusive and resilient circular economy.

Digital infrastructure and its carbon footprint

Although digitalization has undeniable advantages, it is not without risks, such as environmental costs.

The negative impacts stem in particular from the significant energy consumption and greenhouse gas emissions generated during the use of digital infrastructure, equipment and IT networks. Political and private initiatives aim to reduce these effects and achieve the goal of climate neutrality, proposing solutions such as more energy-efficient technologies, smart consumption management and the adoption of renewable energy sources (Bieser et al., 2020; Gröger et al., 2021; Hintemann et al., 2020a, 2020b; Masanet et al., 2020).

In addition to the operation, the process of extracting and processing raw materials for the manufacture of digital equipment also involves a series of socio-ecological consequences. Added to this is the problem of e-waste, the amount of which is increasing every year and whose recycling is insufficient on a global scale (below 20%) and even at national level in Germany (around 45%) (Baldé et al., 2020; Forti et al., 2020; Umweltbundesamt, 2020).

It is therefore essential that the principles of the circular economy are applied consistently throughout the life cycle of digital products. For home users, the increase in the number of digital devices, most often with a short lifespan, leads to increased resource consumption. Although some devices offer multiple functions that can reduce the need for other devices, it is necessary to extend the life of components by increasing their durability, reuse and recycling. Viable solutions also include modular design and the interchangeability of hardware elements.

It is also necessary to develop effective software update strategies to avoid moral hazard, as well as the creation of open source codes that allow alternative providers to offer repair and update services.

Although the circular economy is seen as an essential tool for reducing environmental impact, its application through digital means can lead to counterproductive effects. A significant example is 3D printing, a technology that consumes a lot of energy and generates losses of raw materials. Moreover, the composite materials obtained become difficult to recycle, and the emissions of ultrafine particles raise health concerns. Another relevant aspect is the rebound effect, similar to that observed in energy efficiency. Reducing costs through efficient technologies can stimulate consumption and production, partially or completely canceling out sustainability gains. Thus, the transition to a digital circular economy requires a careful assessment of the balance between benefits and externalities.

The social challenges of digitization

Emerging digital technologies, such as artificial intelligence, automation and 3D printing, are profoundly transforming the dynamics of the labour market. These changes are not limited to the modernisation of existing activities, but also involve a substantial restructuring of the skills required, with potentially major effects on the economic and social balance.

As new professional fields emerge, such as software development, data analysis or cybersecurity, repetitive jobs, especially in industry, logistics and administration, are starting to disappear. Tasks that can be automated are increasingly vulnerable to replacement by technology.

Global forecasts indicate that millions of jobs could be eliminated in the coming decades, especially in sectors where routine work predominates. As a result, workers are increasingly under pressure to adapt, acquiring digital skills, critical thinking and the ability to collaborate with intelligent systems.

This technological transition does not affect all social groups equally. Without clear support measures for vocational training and inclusion, there is a risk that certain groups, such as the elderly, those with low levels of education or those from disadvantaged regions, will be excluded from the labor market.

This transition is not uniform and risks deepening social inequalities, if support measures for retraining and professional inclusion are not implemented early and on a large scale. Without coherent education policies and equitable access to continuing training, already marginalized populations such as older people, those with low levels of education or those from disadvantaged areas may be pushed out of the labour market.

Thus, the restructuring of the labour market in the era of advanced digitalisation should not be seen only as a technological issue, but as a complex social challenge, requiring multi-sectoral responses. Investments in adaptive education, lifelong learning, labour protection policies and the stimulation of social innovation become key elements for building a future of work that is both productive and inclusive.

Significant developments in the digital transformation of the labor market in the the European Union Member States

In the period 2019–2023, the European Union Member States recorded significant developments in the digital transformation of the labor market, with direct implications for the structure of employment and the skills needed. The skills of digital citizens, the ability of firms to adopt new ones, the impact of the COVID-19 pandemic, and participation in continuing education are just a few of the elements that are taking care of these transformational technologies.

In 2021, only 54% of EU citizens aged 16-74 had at least basic digital skills. The countries with the highest percentages of people with basic digital skills were Finland and the Netherlands (79%), followed by Ireland (70%), while Romania was among the countries with the lowest percentages, with only 28% of citizens having basic digital skills in 2021.

In 2023, the European average of citizens with at least basic digital skills reached 55.6%, reflecting a slow but steady evolution. However, differences between Member States remain considerable (Table 1).

Table 1: Percentage of citizens with basic or higher digital skills

Country	Percentage (%)
Denmark	96.2
Netherlands	83
Finland	79
Ireland	70
Sweden	67
EU Average	55.6

Source: Eurostat data (2023)

Data from 2023 on the level of basic or higher digital skills among the population in the European Union reveal a significant polarization between the north-west and the east of the continent. Denmark is at the top of the ranking, with an impressive 96.2% of citizens having at least basic digital skills. This performance reflects an education system well adapted to the demands of the digital age and a coherent public policy that actively supports digital inclusion.

The Netherlands (83%) and Finland (79%) confirm this Nordic trend in digital performance, demonstrating that effective digitalization is not only based on technological infrastructure, but also on equal access to training, as well as on a consolidated digital culture at societal level. Ireland (70%) and Sweden (67%) follow the same pattern, albeit with somewhat more moderate percentages, but still above the Union average.

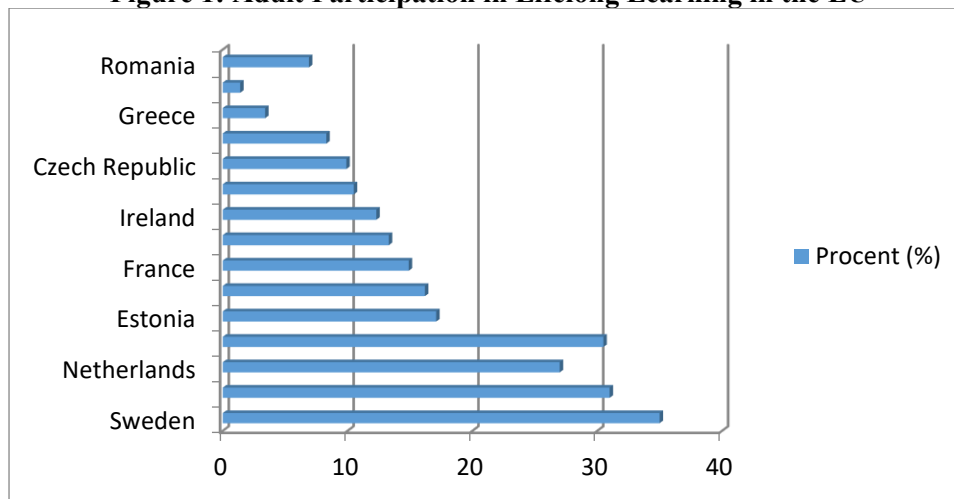
Significantly, the EU average, at 55.6%, marks a critical threshold separating countries that have integrated digitalisation into their daily and professional lives from those that still face structural challenges in this area. This average value suggests the existence of substantial internal imbalances, where the outstanding performances of some countries are negatively offset by the lags of others.

More than a simple statistical ranking, these percentages indicate the depth of the digital divide that can affect citizens' access to economic opportunities, modern public services or democratic participation. In the absence of a common strategy to support low-performing countries, this imbalance risks turning into a new form of exclusion – this time digital – that reproduces pre-existing socio-economic inequalities.

Furthermore, the 2023 data on adult participation in lifelong learning (ages 25–64) continue to reveal a deeply uneven landscape across the European Union. The divide between high-performing Northern countries and underperforming regions, particularly in the South-East, remains striking and persistent.

Sweden and Finland maintain their leading positions, with participation rates that remain close to the upper benchmark in the EU, confirming the resilience of educational models that prioritize adaptability, open access, and the normalization of continuous up skilling (Figure 1).

Figure 1: Adult Participation in Lifelong Learning in the EU



Source: Eurostat data (2023)

These systems are not only structurally robust but also culturally embedded, where lifelong learning is regarded as a societal standard rather than an exception.

Denmark, the Netherlands, and Estonia also remain aligned with this upward trend, reaffirming their strategic commitment to fostering personal and professional growth among adults. In these countries, lifelong learning operates not as an auxiliary policy but as an integral component of labour market strategy and social cohesion, backed by targeted investments and mature institutional frameworks.

Despite this encouraging performance in some regions, the overall EU average remains modest, hovering around 9%, which continues to fall short of strategic benchmarks set by European development frameworks. This persistent stagnation suggests that, in many member states, adult education is still treated as secondary to formal schooling, rather than as a foundational pillar of economic resilience in a rapidly evolving digital society.

Digitization of Enterprises in the European Union

In the context of accelerated digital transformation at a global level, the digitization of enterprises in the European Union has become not only a vector of competitiveness, but also an essential condition for economic survival in times of crisis. The data available for 2022 highlights a fragmented reality: although, on average, 53% of European companies have implemented or accelerated digitalization processes, the differences between enterprise categories remain significant (Table 2).

Table 2: Degree of Business Digitalisation in the EU

Type of Enterprise	Percentage that adopted digitalisation (%)	Remarks
Large enterprises	63	Better access to resources and know-how
Small enterprises	30	Financial constraints and lack of digital skills
EU average	53	Average across all company categories

Source: Eurostat data (2023)

According to Table 2, 63% of large enterprises have adopted digitalization measures, benefiting from wider access to financial resources, advanced IT infrastructure and internal technological expertise. In contrast, only 30% of small enterprises have managed to invest in this direction. This structural discrepancy reflects systemic barriers such as lack of funds, digital skills deficit and the absence of institutional support adapted to the needs of micro-enterprises. In the absence of specific policy interventions, these differences risk deepening, contributing to a polarization of the market: large firms become increasingly efficient and automated, while small enterprises remain vulnerable to competitive and technological pressures.

COVID-19 pandemic an influencing factor of the digitalization process

The COVID-19 pandemic has accelerated the digitalization process in the European Union, causing companies to quickly adopt these technologies to respond to new market conditions. Investments in digitalization have increased significantly during this period, although there have been a number of economic challenges during this period, and against the backdrop of the restrictions imposed by the pandemic and the need to maintain economic activity in safe conditions, European companies have had to invest rapidly in digital solutions. Even though many of them reported financial losses in 2021, in the following year almost half increased their budgets for digitalization (Table 3).

Tabel 3: Impactul COVID-19 asupra digitalizării (2021–2022)

Year	Indicator	Value (%)	Observations
2022	Increased investment in digitalization	42	Responding to increased demand for online services
2021	Decrease in sales (total companies)	49	SMEs most affected
2021	Small businesses disproportionately affected	—	Limited resources, difficult adaptation

Source: Eurostat data (2022, 2022)

The data in Table 3 highlights that digitalization was essential for business survival in the pandemic context and that not all firms had the capacity to make this leap. SMEs were particularly exposed to risks, as they had fewer resources to support the technological transition (Table 4).

Table 4: Evolution of investments in digitalization and adoption of digital technologies (2021–2023)

Indicator	2021	2022	2023
Proportion of SMEs with basic digital intensity (%)	22	41.2	57.7
Proportion of SMEs using cloud computing (%)	16	34	38.9
Proportion of SMEs using data analytics (%)	14	—	33.2
Proportion of SMEs using artificial intelligence (%)	8	—	8
Proportion of SMEs using big data (%)	14	—	14.2

Sursa: Eurostat, Eurostat Digitalisation 2023, Eurostat Digital Economy and Society Index

The proportion of small and medium-sized enterprises (SMEs) with core digital intensity reflects the use of at least four of the twelve digital technologies considered essential. In 2023, this indicator reached a level of 57.7%, marking a significant increase compared to the value of 22% recorded in 2021. The adoption of digital technologies has intensified considerably during this period. The use of cloud computing services increased from 16% in 2021 to 38.9% in 2023, while the share of SMEs using data analytics reached 33.2% in 2023. On the other hand, the implementation of artificial intelligence remained constant at 8% in the period 2021–2023, indicating a stagnation in the adoption of this advanced technology. Also, the use of big data stood at 14.2% in 2023. This data highlights the progress made in the adoption of digital technologies by SMEs, although the European Union's goal of achieving a basic digital intensity of 90% by 2030 is still far from being achieved.

Economic dimensions of inequalities in access to innovation in the implementation of digitalization

Digitalisation plays an important role in boosting economic growth, business efficiency and market competitiveness. However, the unequal access to digital technologies between large companies and small and medium-sized enterprises (SMEs) poses significant economic and social challenges. This imbalance can negatively affect market dynamics and overall economic cohesion.

Large companies have a considerable advantage, benefiting from financial and technological resources that allow them to quickly deploy advanced digital solutions, use high-performance digital infrastructures and manage large volumes of data, which gives them a solid competitive advantage. In contrast, SMEs face a number of difficulties, such as limited access to finance, a lack of the necessary digital skills among staff and challenges related to technological interoperability. These barriers restrict SMEs' ability to adopt new technologies and adapt to the demands of the ever-changing digital economy.

This situation favors a sharp economic polarization, in which markets tend to be dominated by a few main players, with a negative impact on strategic sectors, such as sustainable waste management or local circular production. The exclusion of SMEs from these areas can reduce the diversity of economic supply and the capacity for local innovation, leading to a uniformity of solutions dictated by the standards of large corporations.

To mitigate these effects, public policies need to focus on supporting the digitalization process in the case of SMEs through concrete measures, such as subsidies for the acquisition of digital technologies, training programs adapted to market needs, stimulating collaboration between SMEs and innovation centers, and simplifying bureaucratic procedures related to the implementation of new technologies. Without these measures, the digital transition risks increasing inequalities, becoming an exclusive process that deepens economic segregation on a digital basis. Recent data from the European Union supports this observation: in 2023, only 57.7% of SMEs reached a minimum level of digital intensity, a modest increase compared to 2021, but still insufficient to reach the 90% target proposed for 2030. Furthermore, the adoption of advanced digital technologies is still low, with only 38.9% of companies using cloud computing services and 8% having implemented artificial intelligence. Employee training in digital skills also remains uneven, with only 22% of SMEs offering such programs, compared to 70% of large companies.

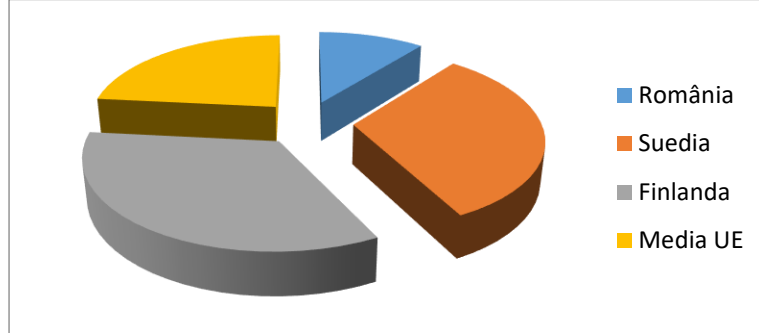
We can say that access to digital innovation not only limits the economic potential of SMEs, but also increases the risk of market polarization and the structural exclusion of essential sectors from modernization processes. Therefore, integrated, inclusive strategies are needed to ensure a fair and sustainable digitalization, capable of supporting both sustainable economic development and social cohesion across the European Union.

Regional disparities in digitalization implementation

The digitalization process in the European Union, although accelerated in recent years, reveals large differences between the regions of the EU member states, both in terms of technological infrastructure and the institutional and economic capacity to support the digital transition. These discrepancies are more visible among small and medium-sized enterprises (SMEs), which, in the absence of coherent support policies, face major difficulties in adopting digital technologies.

Northern European countries – such as Finland, Sweden or Denmark – stand out for a high rate of basic digital intensity among SMEs, supported by innovative ecosystems, high-performance infrastructure and an advanced level of digital skills among the active population. In contrast, Central and Eastern European economies, including Romania, Bulgaria or Hungary, continue to register levels below the European average in terms of both the use of technologies such as cloud computing, artificial intelligence or data analysis, and investments in digital training of employees (Figure 2).

Figure 2: Proportion of SMEs with basic digital intensity (%)



Source: Eurostat, Digital Economy and Society Statistics (2023)

These structural gaps are the result of a combination of factors: historical gaps in the development of digital infrastructure, limited access to financing for digitalisation, and a low integration of new technologies into SMEs' business strategies. Furthermore, the absence of adapted regional policies, the lack of functional public-private partnerships and chronic underfunding of digital literacy programmes contribute to maintaining these inequalities.

This digital fragmentation is not only a technological problem, but also an economic and social one, with direct effects on the competitiveness of local economies, the capacity for innovation and social inclusion. Without strategic interventions, the differences between high-performing and lagging regions risk widening, generating a dual economic climate, in which only part of the Community space fully exploits the benefits of digitalisation.

Therefore, reducing these disparities cannot be achieved solely through the free market. Active involvement of European and national institutions is needed in formulating differentiated policies, adapted to local realities, which include measures to increase SMEs' access to emerging technologies, develop digital skills in disadvantaged areas and create support networks for innovation. Only through an integrated, balanced and equitable approach can digitalisation become a real tool for economic and social cohesion within the European Union.

Adapting legislation to new models of the digital circular economy

The rapid expansion of digital business models, such as the collaborative economy and cross-border online sales, has highlighted a major structural problem: current legislation fails to keep pace with the accelerated pace of technological innovation. For example, platforms such as Uber have revolutionized entire sectors, but have generated significant difficulties in regulating legal liability. In many countries, it is not clear who is responsible in the event of incidents: the platform, the service provider or the user. This lack of legislative clarity complicates the application of justice and the protection of consumer rights.

Furthermore, the principle of the "right to repair", which should allow consumers to repair their products in an affordable way and extend their lifespan, is still insufficiently regulated, especially in the case of digital or refurbished products. In many European markets, legislation does not provide a clear framework for quality standards or guarantees for these products, creating an uncertain environment for consumers and businesses alike.

On the other hand, data protection and privacy remain a major challenge. While the General Data Protection Regulation (GDPR) is a solid framework in the EU, its implementation and adaptation to new technologies, such as artificial intelligence or IoT (Internet of Things)

applications, is still ongoing. The lack of specific rules for these technologies increases the vulnerability of users, who are often unaware of how their personal data is collected, processed or used.

In addition, emerging technologies that consume significant amounts of energy, such as blockchain and cryptocurrencies, pose additional challenges. Blockchain, known for its transparency and security, is however criticized for its environmental impact, given the energy-intensive nature of processing transactions on public networks. This presents decision-makers with the need to rethink the legislative framework to encourage the development of environmentally sustainable technologies, aligning digital innovation with international climate commitments, such as the European Green Deal.

Conclusions

The digitalisation of the circular economy brings many opportunities, but also significant risks that may affect the sustainability and fairness of the transition. In the absence of integrated policies that take into account the ecological, social, economic and legislative dimensions, these risks may amplify inequalities and undermine technological progress.

The lack of a flexible legislative framework that regulates the market for refurbished products, data protection and the right to repair generates uncertainties for consumers and companies. In addition, the limited access of small and medium-sized enterprises (SMEs) to technology and digital resources risks marginalising them, widening the gap with large corporations.

The impact on the environment may also be negative if strict standards on the energy efficiency of digital infrastructures are not imposed. In this context, the deficit of vocational training adapted to new technological requirements worsens the vulnerability of the workforce in sectors affected by automation.

Also, the digital disparities between the Member States of the European Union, with the Nordic countries much better positioned than the Eastern countries, fuel the risk of economic polarisation. Without international collaboration to harmonize regulations and support sustainable trade, these risks may lead to a market homogenization dominated by a few strong players, affecting local diversity and innovation. In conclusion, the digitalization of the circular economy requires a strategic and comprehensive approach, aimed at minimizing risks and ensuring a fair and sustainable transition.

The period 2019–2023 was a key stage in the digitalisation process at the European Union level, significantly accelerated by the COVID-19 pandemic. This transformation generated important opportunities for the development and modernisation of economies, but also highlighted major structural disparities between Member States, in particular between the Nordic countries and those in Central and Eastern Europe, such as Romania.

The persistence of digital and skills gaps between regions directly affects the competitiveness of small and medium-sized enterprises, which face difficulties in adopting new technologies, an essential condition for integration into the digital economy. At the same time, small enterprises continue to face difficulties in adopting digital technologies, which affect their capacity to innovate and competitiveness. The lack of coherent support tailored to their needs contributes to maintaining these differences. Thus, the digitalisation process risks becoming a factor that amplifies economic and social inequalities, if not supported by coherent public policies and adapted interventions.

A positive signal is the increase in women's participation in the technology sector, which indicates an evolution towards inclusion and diversity. However, in order to maintain and amplify this trend, it is necessary to continue and strengthen policies that support work-life balance, as well as to eliminate systemic barriers.

For the digital transformation to become a real driver of sustainable and equitable progress, an integrated approach is indispensable, which includes the development of digital skills through adapted education, facilitating SMEs' access to financing and specialized advice, promoting gender equity and creating a flexible social framework capable of managing the risks generated by automation and changes in the labour market.

We can say that digitalization should not be an elitist process, accessible only to certain regions or social categories, and the digital future depends on the capacity of public and private actors to collaborate strategically to reduce disparities and ensure the inclusion of all regions and social categories in the benefits of the digital revolution. With an integrated vision and coherent policies, the digital transition can become a driver of equity and sustainable development in the European Union.

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