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Circular Economy and Information Technologies: Identifying and Ranking the Factors of Successful Practices

Wishal Naveed [1], Majsa Ammouriova [2], Noman Naveed [3] and Angel A. Juan [4,*]

1 Ernst & Young Nederland LLP, 3011 XZ Rotterdam, The Netherlands
2 Computer Science Department, Universitat Oberta de Catalunya, 08018 Barcelona, Spain
3 Institute of Business Administration, University of the Punjab, Lahore 54590, Pakistan
4 Department of Applied Statistics and Operations Research, Universitat Politècnica de València, 03801 Alcoy, Spain
* Correspondence: ajuanp@upv.es

Abstract: Optimal resource utilization and sustainability are gaining importance in the last decades, raising awareness about the circular economy principles. The transition toward the circular economy demands appropriate culture, environment and technology. The developments in information and communication technologies could form the base for these requirements. Our study targets identifying factors that affect the implementation of circular economy principles. In addition, the role of information technologies in their implementation is targeted. A structured literature review was conducted to define these factors. These factors are categorized into four categories: cultural, automation, sharing, and measurement. The importance of these factors is ranked based on a questionnaire. The results show that the found factors are considered success factors in implementing circular economy practices. With respect to categories, the highest impact was noticed by the cultural category, emphasizing the impact of human factor, relations, and communication on the success of circular economy policies. In addition, factors related to appropriate infrastructure and data collection support the transition toward circular economy.

Keywords: circular economy; sustainability; resource utilization; information and communication technologies

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1. Introduction

The circular economy (CE) concept has gained considerable momentum in industry practices, policy making, and academia to promote sustainable economic development in the recent decade. Dominant linear economy models present serious threats to world sustainability by over-exploiting natural resources, which are vital for the survival of humanity and the planet. CE presents itself as a viable alternative to the linear economy and focuses on the optimal use of resources. It involves designing products that have a longer lifespan and can be reused, repaired, refurbished and re-manufactured, while retaining the functional value of the product—rather than just recovering the energy and material they contain—and eliminating waste as most as possible. Advancements in information technology resources—such as the internet of things (IoT), artificial intelligence (AI), cloud computing, virtual reality, big data and analytics—play a vital role in enabling circularity-based models. They require a complete repositioning in delivering a product to servitized business models, wherein companies retain the ownership of hardware and sell the product use rather than the product itself [1]. This business model is the backbone of a circular economy where products are made smart with sensors and kept in the best conditions by utilizing real-time information through predictive and prescriptive analytics.

With the massive rise in digital transformation at the organizational level, technological innovations are at an all-time high. Simultaneously, digital tools—IoT, big data and AI—have induced a design modification in trends of industrial production and delivery services globally. Consequently, the gravity of environmental threats has put CE and sustainability at the top of corporate agendas [2]. It brings about this decoupling of value creation by the optimal utility of finite natural resources leveraging a combination of efficient, productive, waste-reduction strategies and restoration-oriented analytics to keep the product, its components, and materials in circulation for long [3]. Information technology resources are considered critical enablers of accelerated transition to CE.

The CE contributes to reducing the waste produced at the end of a product life cycle, aiming at achieving the maximum utility of natural raw materials. For example, Mud Jeans are lending jeans to consumers under the "lease a jeans" model by creating easy online communication access [4]. After return, depending on the jeans' condition, they are either up-cycled as vintage or recycled. The company then reuses the materials in a new production with 50% organic and 50% recycled cotton. With over 200,000 million jeans sold a year, it makes a massive difference in the usage of cotton. Similarly, Philips is using the "pay per lux" model to change from a linear economy to CE [5], wherein the customers use the light without owning the hardware, termed as data products—i.e., products based on data-driven insights. Philips deploys data monetization strategies in designing such a flexible product. Economies of scale have great implications in this area. Instead of treating the initial investments as cost centers, they should be considered a new revenue stream with a world of possibilities. For example, Rolls Royce uses the "power-by-the-hour" business model, and the airlines employ their services instead of buying the engines [6]. They track the real-time activities and information of engines using onboard sensors (IoT technologies). Received data are then adequately analyzed, and preventive methods can be applied. Accordingly, risk can be reduced early, which assists in increasing the engine life span which is one of the base principles of CE [7]. Organizations can realize significant benefits by capitalizing on sustainable development, i.e., making strong customer and community relations, gaining competitive advantage, and creating brand new revenue streams.

With CE principles making their way into legislative agendas and prices of natural resources rising, businesses will have no option but to make a sustainable choice. Pioneers such as Rolls Royce, Philips, and Google enjoy a competitive edge by deploying eco-friendly techniques. European Union's 2020 Circular Economy Action Plan (CEAP), guiding Europe's industrial strategy, helps stabilize climate change to preserve the natural environment. Its objective is to ensure that items reaching the shelves and sold in the market are designed to last multiple life-cycles—restricting the single-use to tackle obsolescence—and are convenient to reuse and refurbish, thus utilizing recycled material increasingly (http://ec.europa.eu/environment, accessed on 1 April 2022). EU countries adapt different strategies and vary in their transition toward CE [8], and, accordingly, actions should be defined to support the transition. Despite this difference in transition among EU countries, CE is expected to increase European GDP by 11%, and profit of around USD 1.8 trillion by the year 2030, and will save material costs by around USD 1 trillion [9].

Despite all the stated benefits, legislations, and different adapted strategies, the adaption of CE strategies in industrial practices has so far been modest. Literature findings also suggest that the main obstacles impeding CE transition are more organizational than technological [10]. Therefore, several practitioners have voiced the necessity of an enhanced understanding of organizations' digital and circular transition, termed Smart CE [11]. Smart CE is a rising field with the link between corporate technological capabilities, resource orchestration, and circular strategies. As a result, there is a knowledge gap in exactly what internal resources and capabilities are required to effectively leverage data and analytics that impact a company's performance and mechanisms rooted in established management. Hence, the importance of IT resources in the CE process motivated us to explore and prioritize the factors that could positively influence the CE process execution. This paper will address this gap and provide a prioritization-based framework for successful implementation. To achieve the study aim, firstly, we conduct a systemic literature review (Sections 2 and 3), and identify a list of factors that positively impact the implementation of CE using IT (Sections 4–8). Then, a questionnaire survey is used to validate the literary findings (Section 9), and a link to sustainable development goals is shown. The main contributions of the paper are highlighted (Section 10). The in-depth study will serve as a knowledge base for consultants, change agents, researchers and industry experts to develop new and effective strategies for successful CE progression. The current study limits the success factors to manufacturing and production sectors. These sectors were selected as an initial study to define success factors to transfer into the circular economy.

2. Circular Economy and Information and Communication Technologies

The circular economy has gained increased interest in the last decade. However, because of the lack of a unified definition, this term becomes an umbrella term driven by its core principles, such as resource efficiency, addressing structural waste, catering to multiple product lifespans and performing end-of-life activities (closing the loop) [12]. One of the most comprehensive definitions of CE is given by the Ellen MacArthur Foundation. They define it as a "system restorative and regenerative by design, which aims to maintain products, components and materials at their highest utility and value" [13]. Various "R" frameworks are associated with the drivers of CE, such as 3R, 4R, and 6R. For example, 3R refers to "reduce"-, "reuse"- and "recycle"-interrelated concepts—e.g., reusing an item through up-cycling or converting its parts into a valuable matter for recycling aimed at reducing the consumption of raw materials. In the 4R framework, "recover" is added and emphasizes the significance of recovering the energy leakage implanted in waste by deploying incineration processes [14]. Then, "redesign" and "re-manufacturing" were added to the 6R framework to indicate the designing of products for utilizing resources from earlier life cycles and involving secondhand parts. Recently, the 9R framework was defined by "rethink" to maximize product use through sharing mechanisms, "repair" to maintain and fix defective parts, "refurbish" to reinstate a used item and upgrade it, and "repurpose" to use discarded parts in a product or service that has another purpose [15].

This paper plays multiple key roles from introducing innovation in production processes as well as the promotion of sustainable strategies as mentioned in the European sustainable development goals (SDGs). It is vital to highlight the fact that sustainable production promotes CE by not only developing long-lasting products, but also by creating a community of end users that are oriented toward sustainability, who will be representative of this novel socio-technical system by becoming leaders in supporting this transition and green interactions among technology and people [16,17].

In order to accelerate global growth and competitiveness, government organizations all around the world are incentivizing public and corporate enterprises by taking tax initiatives to favor zero carbon emissions. Sustainable production at the industrial scale has taken central place to achieve that goal, especially in European strategies, i.e., Horizon 2020, the 9th Framework Program-FP9 and other sectoral policies [18]. This is where most managers are having a hard time extending this concept of CE for the development of interconnected models and symbiotic networks to optimize market supply and gain economies of scale. Therefore, the methodologies put forward by employing Industry 4.0 promote the linkage between circular economy and sustainable production at a global scale depicting a certain complementarity to bring about the integrated and holistic synergistic industrial network/systems. The literature also suggests that the future of enterprises lies in this symbiosis of circular economy and technology [19–21].

This combination has grabbed the attention of not only strategic, but also operations management. The reason is the obsolete models, utilizing more fossil-based energies and creating waste that needs to be redesigned as per the SDGs. For this matter, technology offers a solution in the form of closed-loop production systems by means of Industry 4.0 technology to fill the existing gap in the literature and letting it guide us as in forming new models as tools for strategic management [22].

Advancements in information and communication technologies support the realization of CE. Mishra and De [23] explored energy-yielding techniques in 5G cellular technologies offering control replenishment followed by subsequent energy and resource saving. Likewise, Hatzivasilis et al. [24] suggested a disruptive industrial IoT protocol that was tested on the wind parks 5G industrial network.They found that this approach is fast and energy-efficient. Cloud computing offers de-materialization possibilities. For example, the online video streaming model (Netflix, Amazon Prime, HBO, etc.) provides not only hefty benefits to the companies, but also saves environmental resources in the process. The carbon footprint might be reduced using advanced technologies, such as blockchain, which serves to increase the performance and efficiency of IoTs in edge-computing—i.e., computation is carried out closer to the sources of data in a communication network. Cloud-based rental offering assists in reducing the environmental footprint of tools using sensors, data analytics and networking [25]. Advancements in cloud computing include cloud manufacturing, which is a novel business model encapsulating segregation through the componentization, desegregation and optimization of production resources [26].

Finding solutions to problems in the context of sustainability was achieved by utilizing and developing different approaches. Zhang et al. [27] assessed a solution for job-shop scheduling in real time to increase production efficiency with energy savings. Hao and Yue [28] reviewed a multi-modal transport system, based on dynamic programming, that allows for optimizing the routes and modes of transport, while emphasizing resource savings. Gatzioura et al. [29] proposed a hybrid system to enhance decision support in CE transition. The system assists industrial experts in identifying potential resources and symbiotic partners, boosting the firm's performance in line with CE principles. Li et al. [30] examined a hybrid model for planning re-manufacturing by integrating case-based reasoning with blockchain, contributing to a decrease in energy requirements and emissions.

A further solution approach involves the incorporation of machine learning (ML) methods. These are algorithms able to adapt, learn and evolve. Taylor and Sours [31] proposed data-driven and ML approaches to manage and prevent corrosion, enhancing material efficiency and asset preservation, while Zhou et al. [32] assessed a CE evaluation model based on support vector machine (SVM) integrated with a heuristic algorithm for tuning hyper-parameters in iron and steel enterprises. Neves Da Silva and Novo [33] emphasized the role of monitoring systems and centers for waste management and the optimization of resource consumption (water, energy, etc.) to commercial and industrial clients utilizing ML techniques. These examples show the applications of ML in applying CE principles.

3. Research Methodology

In order to identify success factors impacting the application of CE, we conducted a systematic literature review based on the protocols presented in Kitchenham and Charters [34]. Our study is followed by a questionnaire survey that experts examine to rank the identified success factors. For literature extraction, we considered the following six digital libraries: IEEE Xplore, ACM Digital library, Springer Link, Wiley Inter Science, Science Direct, Google Scholar, and IET Digital libraries based on the recommendation of Chen et al. [35] and Zhang et al. [36]. The selected search keywords are crucial in retrieving articles related to the research topic. Thus, we concatenated several keywords using OR and AND operators. The searched keywords are ("Success Factors" OR "ITEMS" OR "Matrices" OR "Aspects" OR "Elements" OR "Drivers" OR "Variables" OR "Motivators") AND ("Industry 4.0" OR "I.4.0" OR "Information technology solutions" OR "Analytics and big data solutions" OR "Digital technologies") AND ("Sustainable development" OR "Circular economy" OR "Sustainable production" OR "Manufacturing industry").

The published work found in the digital libraries was further examined to decide which articles to include in the study and which to exclude. The included articles should be written in English, the results in the articles should be based on primary data, the articles discuss the IT resources in CE, and the articles must elaborate the influencing factors of IT implementation in CE. The excluded articles do not provide a detailed discussion of IT in the CE paradigm. In addition, if two articles based on studies from a research group are considered, only the most detailed one is included in the study.

The selection of the articles was based on the tollgate approach developed by Afzal et al. [37]. The tollgate approach aims to refine the selection of articles along three phases concerning the study objectives (Figure 1).

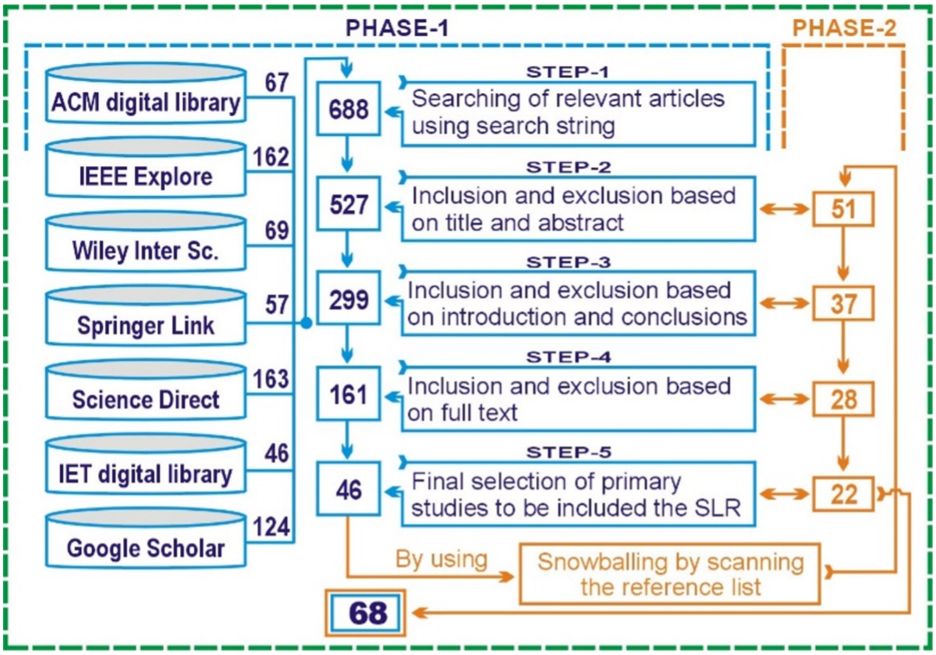

Figure 1. Application of the tollgate approach.

Following the described procedure, we found 688 articles in the selected digital libraries matching our search keyword. Then, the number of articles was reduced to 68 after applying the tollgate approach. Figure 2 shows the increased number of publications (of any type, not only articles) on the CE paradigm using IT resources in the last two decades, according to Google Scholar. In particular, these numbers were obtained using "circular economy" AND "IT" as search keywords. One can notice the sharp increase that has taken place during the last decade, specially since 2015.

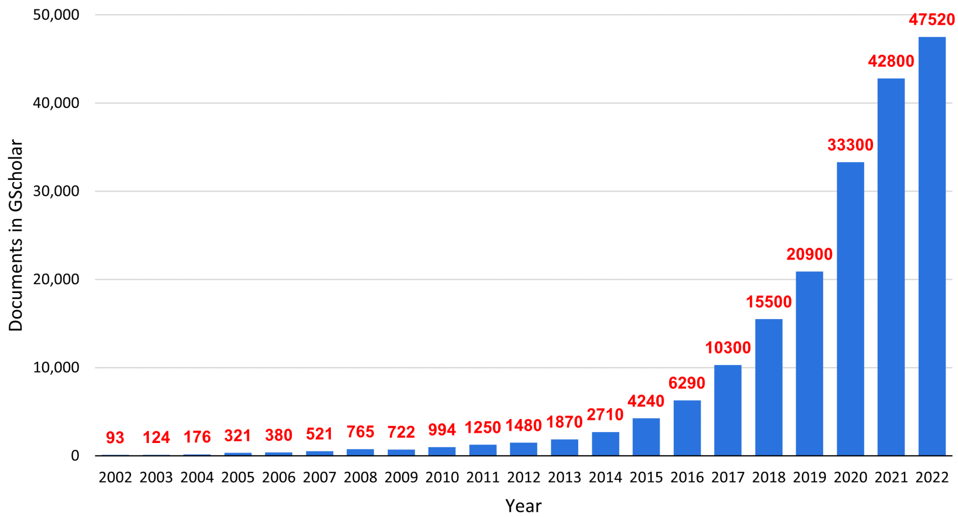

Figure 2. Publication trend of CE paradigm using IT resources in the last decade.

4. Categorizing Success Factors Impacting Application of Circular Economy

According to the review of the 68 selected articles, the success factors are identified. These factors answer the study research questions. We classified these factors into the measurement, culture, sharing, and automation clusters. These factors and their categorization are shown in Table 1.

Table 1. List of found success factors and their categorization.

Category	No	Success Factors
Cultural	SF01	Effective Strategy Formulation by Correspondence among IT and CE Practitioners
	SF02	Developing Economic Policies/Agendas in Support of CE Activities
	SF03	Designing an Enterprise's IT Architecture in Compatibility with Cloud Services
	SF04	Formalize Relationship between Decision Makers Worldwide
	SF05	Machine-to-Machine Communication Ethics
Automation	SF06	Lean Production or Circular Design Strategies
	SF07	Sustainable Technological Infrastructure Development
	SF08	Information Safety and Security Ethics
	SF09	Reverse Logistics
Sharing	SF10	Top Management Commitment
	SF11	Product Service System
	SF12	Industrial Symbiosis
Measurement	SF13	Develop Organizational Goals in Coordination with CE by Focusing on Process Automation
	SF14	Product Design using AI
	SF15	Setup Effective Monitoring System to Gauge Current Performance against Developed KPIs
	SF16	Smart Product for Data Collection

The measurement class refers to those factors emphasizing the importance of setting up measurement and monitoring systems, environmental management systems (EMS), to track the progress in decision making in line with sustainable development goals [38,39]. The benefits and obstacles of adapting these systems have been globally studied, especially in European countries. For example, the EU Eco-Management and Audit Scheme (EMAS) and ISO: 14001 standards are the leading EMSs that enable a corporation to manage, monitor, and enhance environmentally sustainable practices [40]. Measurement helps to determine the progress in the intended direction. However, two critical steps should be verified while setting up monitoring systems: setting correct parameters and promoting the right ones.

Other factors are related to the way of life carried out by groups of people, and how individuals behave and deal with things, cultural environment, and other individuals. The communication and mutual understanding between groups increase when the groups are from the same culture, i.e., knowledge, beliefs, and capabilities. Increasing the information sharing within departments and organizations can bring a significant change in current unsustainable activities through the continuous involvement of all the potential actors of CE. Since this study requires experts and practitioners from different departments who used to work in different ways, a culture of harmony and trust has to be built to successfully implement CE using IT [40]. In the scope of this article, culture encapsulates any action that enables the sharing of resources and information in terms of tools or market platforms, and consumer business attitudes to accelerate CE.

The third class of success factors, sharing, refers to practices related to data sharing and transparency. Sharing collected data using protected means to be best utilized should be highly prioritized for practitioners and enterprises. Specific policies must be established for sharing, i.e., among practitioners, machine-to-machine and company-to-company. The big data collected through smart machines come directly from individuals and households, so privacy invasion could be an ethical concern. In the past, these kinds of personal data collected from social media websites have been used maliciously to manipulate big decisions, so sharing parameters and principles should be established and strictly followed. Enterprises should also incorporate feedback loops to earn the public's trust and verify the data simultaneously.

The last class refers to digital technology and automation. These technologies save time, effort, and money and play the most important role in enabling the transition toward CE through IoT, big data and analytics. They help develop models to gather and analyze big data to form insights, which help in efficient and informed decision making. We can think of automation as a buffer that facilitates the relationship between two parties and transitions between two economies, linear to circular. These processes require standardization to achieve automation which is the main reason for integrating information technology to implement CE.

5. Cultural Success Factors

As listed in Table 1, these factors refer to strategies and practices to enhance communication between practitioners. These factors are the first five factors in Table 1, SF01 to SF05.

5.1. Effective Strategy Formulation by Correspondence among IT and CE Practitioners

Established strategies that motivate people and industries to adapt CE practices contribute in increasing awareness of CE. These strategies aim to guide consumers to make well-informed optimal choices and ask for guidance when necessary to contribute toward a more sustainable economy. As a result, innovative research in the field of CE and CE transition increases. For example, smart specialization strategies help member regions and states to increase awareness of the connection between CE and IT, such as the European structural and investment funds (ESIF) and, specifically, the European Regional Development Fund (ERDF), ESF (European Social Fund) and Erasmus+. These strategies improve the states' and regions' capacities to implement sustainable and innovative solutions [41]. In addition, these strategies aim to guide the practitioner to make well-informed optimal choices and ask for help when necessary. Considering the growing information overload, people require guidance on how to contribute toward a more sustainable economy (e.g., via different mandatory and voluntary labeling schemes). With the significance of requisite skills for the transformation and the risk of a digital divide, investing in people's capabilities is essential. This will build on top of ongoing initiatives, such as the new Skills Agenda for Europe and couple it with support from ESIF and Erasmus+.

5.2. Developing Economic Policies/Agendas in Support of CE Activities

The environmental crisis demands that economies reach zero carbon emissions by 2050. However, emissions have continued to increase in the past decade, according to the UN's Intergovernmental panel on climate change. Most policies in practice encourage the reduction in organic raw materials on the supply side or decarbonizing investments and financial markets, but not on the consumption side. This fact forces to establish practices that ensure reducing emissions while increasing the gross domestic product (GDP). Industry 4.0 can be coupled with the circular economy to decouple economic measures, such as GDP, from the consumption of virgin materials for countries that aim at developing sustainable economies. This approach provides a circularity-based model that can achieve the net-zero goal.

War between the largest fuel exporter (Russia) and the biggest food exporter (Ukraine) has caused panic worldwide. It brings both vital commodities in the short supply, resulting in high inflation, and in turn, poverty and social discontent as "scramble for fuel" are destroying multilateral systems found on the basis of mutual trust and proportionality. As opposed to the harmful impacts of war on the world, every crisis is also an opportunity to do better for the common good. Market disruptions of energy and food supplies post-pandemic and then war have made the governments rethink their reliance on limited countries/suppliers and decide to be self-sufficient. Governments have taken several initiatives in the form of tax reliefs for those coming up with ways to create alternative energy and food production, i.e., hydroponics and wind or solar power sources.

In the third brief of "Global impact of war in Ukraine: Energy crisis" by the UN global crises response group in August 2022, the group has discussed the energy policy measures to balance the urgency and sustainable development by dividing them into short-, medium- and long-term policies (https://news.un.org/pages/wp-content/uploads/2022/08/GCRG_3rd-Brief_Aug3_2022_FINAL.pdf (accessed on 31 October 2022)). Short-term measures involve the implementation of latest technologies, leading to behavioral changes in the utilization of heating, cooling and mobility habits. Achieving this efficiency and demand reductions are the fastest ways and quickest interventions for mitigating high prices. Medium- to long-term measures must corroborate the Paris agreement and SDGs, as recent crises have created an urgent need for renewable energy resources. Inflated prices of fossil fuels present an opportunity to accelerate the efforts toward CE transition, given that renewable energy is the only cost-competitive solution at hand. In order to address bottlenecks in the generation of renewable energy, attracting investment for the expansion of clean energy through decentralized-off grid solutions as well as on-grid connections is required. It becomes important to capture its benefits in a just way to meet the 1.5 °C target for the world.

5.3. Integrating Cloud Services into the IT Infrastructure of an Organization

In the current decade, many consumers have embraced the CE model of reusing and reselling previously owned clothes, furniture, electronics, and so on. They are trading valuable goods on dozens of online platforms, such as Alibaba's Idle Fish for valuable, pre-owned products instead of discarding them. In addition, there has been a shift in people's perception of it, i.e., from "used" to "pre-owned" to "pre-loved". These resale marketplaces allow customers and enterprises to transform un-wanted products into a source of income that extends their life span and reduces production and waste. Digital technology resources and platform economics enable the expansion of these markets beyond garage sales and local charity shops, and the development of a green economy lies in coupling digitization and CE while decoupling GDP and the consumption of virgin materials and fossil fuels.

Cloud computing provides a solid foundation for these sharing platforms while decoupling economic growth from carbon emissions. Goods and services flowing through this sharing aid consumers in finding sustainable solutions to their needs or problems. In addition, clouds employ state-of-the-art hardware, power management, and computing technologies, with high levels of renewable energies, and continuously improve hardware circularity. Cloud computing has aided in limiting the annual yearly increase in consumption of energy to 6%. The little change is due to the advanced improvement in energy efficiency [42].

5.4. Formalize Relationship between Decision Makers Worldwide

Two approaches can be used to achieve an objective: top-down or bottom-up ones. An economic shift worldwide can be better achieved through the top-down approach [43]. In this approach, legislators of countries and decision makers or chairs of international organizations, such as the European Union and the Environmental Protection Agency (EPA) can play a fundamental role in achieving a big shift so that companies operating in those areas will need to follow the laws set by such agencies [43,44]. The goal is to shift a shareholder economy into a stakeholder economy. Governments worldwide are promoting industrial scale-sustainability by introducing various tax and financial initiatives for accelerating transformation towards sustainable development and acceleration of competitiveness and global growth. In this regard, managers face the colossal challenge of expanding the circular economy concept to productive company networks—i.e., creating efficient interconnection models within a symbiotic industrial ecosystem and optimizing the market supply with a sustainable orientation of economies of scale [18].

5.5. Machine-to-Machine Communication Ethics

For continuous improvement using digitization, smart machines need to interact with each other, which in turn creates the need to set up a check-and-balance mechanism for protection against individual's privacy breaks and ethical violations. Organizations receive loads of data. Accordingly, they should set ground rules for data sharing, and algorithms must be tested for biases against any gender, ethnicity, or religion [45]. Digital tools are the key function to achieving this paradigm shift from a conventional to a data-driven model of scientific decision making. Sharing information using protected means should be of the utmost priority for practitioners and enterprises. Specific policies have to be established for sharing—i.e., among practitioners, machine-to-machine and company-to-company. Big data collected through smart systems come directly from individuals and households, so privacy invasion is a serious ethical issue.

6. Automation Success Factors

These factors represent the utilization and incorporation of smart machines and automation in different processes. In this class, four factors are defined and numbered as SF06 to SF09 in Table 1.

6.1. Lean Production or Circular Design Strategies

Lean production discourages mass-production practices and focuses on a system that is aimed at good quality products and customer satisfaction. In this production, non-value-added processes are considered to be waste. To practice the lean concept, it is highly advised to integrate IT tools between production and planning levels as well as supply and demand processes. These tools optimize the value chain because of autonomously controlled and dynamic production [46] and cover all aspects of the design and process flow of products and services through flexible logistics and production systems.The conventional manufacturing process has to be thoroughly revamped to incorporate sustainability at every step. On the contrary, smart machines replace the traditional production hierarchy with decentralized self-organization that is achieved by utilizing cyber–physical systems [47]. The local control intelligence of these systems keeps communication with other active devices and production modules, making the production line modular and flexible. The self-organization of electronics (machines) will take and, in turn, will aid "plug and produce" [48] and go as far as replacing manufacturing units. The acquired data using sensors are examined and processed remotely on the cloud to achieve better results. This method is selected to avoid any inaccuracy, which is the core idea of Poka Yoke.

6.2. Sustainable Technological Infrastructure Development

The infrastructure should be adapted to the requirements of IT for a circular economy [49]. Integrating new technology should be seamless across all departments [50]. If the new infrastructure does not comply with product lines, company's goals and visions, it will fall apart with any change in the outside environment [51]. Companies might face some challenges when implementing Industry 4.0: upgrading machines, errors in data processing, staff skills, cyber-attack, lack of standards and benchmarked processes, and environmental impact caused by non-renewable energy sources as well as skilled human capital to become enablers of CE. Digitization is not the automatic path as it comes with a massive risk of digital divide, where only the wealthy ones can access and utilize available technologies. There is an increasing gap between the labor force: a high-skilled workforce that can operate complex technology, and a low-skilled workforce that is going out of work because of automation. It should be incorporated into sustainability agendas that those affected by circular practices and digitization are compensated at other businesses such as reverse logistics that require a workforce, a win–win situation.

6.3. Information Safety and Security Ethics

The biggest concern in integrating IT is the privacy and security of information, becoming accessible to all sorts of hackers [52]. Zhang [53] indicated that data security has to be of the foremost importance while developing technological infrastructures. For example, despite the state-of-the-art and secure servers of Facebook, Google, Apple and Twitter, they have been victims of hackers because of minor system flaws and bugs. It is crucial to have people's trust in digital solutions. For example, initiatives on cyber-security, e-privacy and the regulations review should ensure that data are gathered, analyzed and shared in a secure environment. Educating people on how and what to safeguard in e-privacy is an important component of this process [41].

Blockchain and cloud computing have a fundamental role in changing enterprises' work environments and the way traditional computing works. Blockchain technology is the safest option, as it does not involve third-party trusted authority interference [54]. Unlike cloud computing, the core principle of blockchain is decentralization, which makes data-tempering impossible and assures integrity, as it does not store all its data in one space [55]. Moreover, as opposed to the cloud, it does not provide a service that costs; it is essentially a technological advancement and a one-time cost which keeps a record of digital assets in a well-distributed ledger [55]. Research suggests blockchain's application in healthcare to deal with patients' records and convert them into a paperless sector.

6.4. Reverse Logistics

The logistics sector will be one of the most crucial enablers of CE for all sorts of product-related tasks aiming at a fast, flexible, safe, economical, efficient, and environmentally acceptable performance of freight transport flows. It is quite the widespread belief that many logistics businesses will boom in the shadow of CE efforts, as they play the role of a mediator from product raw material to end-of-life activities. Recently, it has become unimaginable to speak about reverse logistics without mentioning the circular economy. Logistics 4.0 is created essentially by merging conventional logistic processes with Industry 4.0 technologies. Returns, reselling, repairs, repackaging and recycling constitute the five Rs of reverse logistics.

Recent innovations, such as robotics and AI, can help a firm effectively manage its returns and repairs. Firms can manage their transportation process by incorporating AI in their system flow and teaching machines to determine the products current condition, reducing the need for human capital. The benefits are two-fold: eliminating human discretion leads to fewer errors, and utilizing AI and robotics might cut company's cost in the identification of minor repairs. The application area of AI in reverse logistics is quite broad, for example, decisions about warehousing, transportation, vehicle routing, product collection, sorting, and return forecasting as well as developing and choosing alternatives for reassembling, re-manufacturing and recycling [56]. Organizations should evaluate their return mechanisms, and those that intend to boost their profitability should invest as much thought into their reverse logistics activities as they do into their forward flows.

7. Sharing Success Factors

The success factors falling in the sharing category refer to those involving some type of data and information sharing and exchange. These factors are listed in Table 1 with numbers SF10 to SF12.

7.1. Top Management Commitment

The commitment of top management is an essential success factor for implementing CE at the organizational level. Plenty of innovative projects close because of the lack of support from the top management. The vision and mission are communicated from the top management level. To incorporate the circular economy practices, the organization must change its policies or invest its finances differently and with different aims. Only top-level management can make these decisions. Initially, the organization might incur an extra cost in integrating IT into the organizational infrastructure, which will be from the safe and updated technology, creating opportunities in various markets, producing finance pooling, and minimizing risk.

7.2. Product Service Systems

Product service systems focus on selling services and performance rather than a product, decoupling economic growth from resource consumption. These usage-focused models have been acknowledged as crucial enablers of circular strategies. They are related to resource efficiency and long life cycles. For example, companies retain ownership of products and pay special attention to production quality and resource efficiency. Products are made smart to keep track of their conditions in real time and preventative and predictive analytics are used to catch any fault early and fix it. These systems must be integrated with reverse logistics to manage, swap, and perform end-of-life activities. Embedded services, comprehensive services, integrated solutions, and distribution control are some popular usage-focused models explored by Bressanelli et al. [57].

7.3. Industrial Symbiosis

The mutually beneficial exchange of by-products and waste is called industrial symbiosis. In this process, the industry has a symbiotic relationship in such a way that the waste or by-products of one company become the raw material for the other. Based on nutrient flow and environmental mutualism in an ecosystem, industrial symbiosis requires collaboration and cooperation across stakeholders operating their businesses in relatively small proximity to accelerate CE transition by sharing resources. Frosch and Gallopoulos [58] mentioned this strategy to reduce the impact of industry practices on the ecosystem over 30 years ago. The authors highlighted the need for recycling, conservation and alternative materials, as by 2030, approximately 10 billion people will exhaust the natural resources of critical importance, thereby creating solid waste of 400 billion [59].

Digital technologies offer countless opportunities to smooth industrial symbiosis to efficiently fit into the CE paradigm [46]. Information technologies enable the company to monitor the quality and track the availability and location of energy flows throughout the manufacturing cycle [60]. Therefore, the integration of these technologies can identify potential synergies based on the collected data and establish a mutually advantageous interaction and information flow between companies to match buyers and suppliers [61]. Despite several benefits that digital solutions offer in industrial symbiosis, their industrial practice and application are not very successful at the moment because pre-existing platforms lack industrial symbiosis-related services or the ability to reach a critical number of masses [61,62].

8. Measurement Success Factors

These factors refer to establishment of systems to monitor and collect data. These data could be utilized in decision making or build practices. Table 1 shows these factors as SF13 to SF16.

8.1. Develop Organizational Goals in Coordination with CE by Focusing on Process Automation

Digital tools can result in a very speedy rise of organizations in a highly competitive market by taking advantage of the latest technology. Moving from a linear economic model to a circularity-based model requires changes to the organizational structure. The processing of a task in a highly automated assembly line is deterministic, unlike systems with low-automation. In the latter, more manual labor is involved, causing irregularities. The high automated systems incur a one-time cost for integrating such systems. In the long run, with optimization, the organization starts to enjoy scales of economies, resulting in rapid financial gains.

8.2. Product Design Using AI

AI can support circular product design by utilizing specific data to reduce resource consumption and increase material productivity [57]. With smart products, monitoring becomes convenient, and maintenance costs drop with fewer defaults, resulting in better customer service. Websites and apps connecting companies and their customers help share information on demand and supply [63]. By collecting data of customers' behavior, such technologies help manufacturers to improve product design and development, which meets the needs of end users and increases users' satisfaction [64,65]. Furthermore, AI's ability to detect inconsistencies comes in handy to prevent possible failures by identifying situations that are likely to fail and produce excessive waste. Yang [66] proposed multi-modal information fusion based on the background of big data and constructed the evolutionary neural network of the improved adaptive genetic algorithm. Multi-modal information fusion mainly involves the feature layer and its fusion decision layer. The possibilities of utilizing AI for CE are endless, starting from product design all the way to end-of-life activities—i.e., reuse, refurbishing, and so on. The rule-based information fusion method, the classification-based information fusion method, and the estimation-based information fusion method together constitute the basic techniques of fusing an information layer at different levels [66]. AI can use historical and real-time data from end users and the product itself. Using this data, asset utilization and circulation can be enhanced with various optimization methods. Furthermore, by considering the pricing and demand prediction aspects, AI can also help in inventory management, item-buffering considerations and predictive maintenance.

8.3. Setup Effective Monitoring System to Gauge Current Performance against Developed KPIs

An effective monitoring system involves developing and identifying relative environmental sustainability indicators. Its significance has been emphasized in the literature, as it is vital to implement a set of practices, which in turn allows the monitoring and measurement of organizational performance against sustainability. This will encourage decision makers to choose their actions in line with CE. Sustainability reporting has been studied as a crucial supporting transparency tool to communicate resource-management information and sustainability performance data. A set of quantifiable measures is required to rank organizations' performance while simultaneously communicating their contribution toward CE.

8.4. Smart Product for Data Collection

The central idea behind a smart product is to modify the role of a work piece from a passive part of the system to an active one. These designs have a memory to store and communicate important operational information about requirements as well as user behaviors to bridge the gap between the required resources and coordinate the improvement efforts. Smart products can gather and utilize the information about repetitive actions from sensors and semantic technologies for analysis—-using the context-awareness feature. In addition, collected data allow for visualizations of production process and information flow for any specific product group or as a whole, making it possible to achieve value stream mapping. Developing the current state map indicating waste in products and processes helps assign various future activities in strategic planning. Data gathered from smart products can be stored in a database to be used for studying improvements later. In addition, faults can be identified to initiate failure–repair on other cyber–physical systems automatically. It works like the IoT in fundamental architecture. However, it has greater coordination and combination among computational and physical elements.

9. The Impact of Defined Success Factors

In order to rank the described factors, an online questionnaire was developed. Expert responses are classified into types of responses: positive, negative and neutral. The positive responses indicate that success factors contribute toward the CE transformation, and the negative responses refer to factors with no role in successful implementation. Neutral responses show that practitioners are not entirely aware of the impact of a success factor on CE. Experts were asked to evaluate the success factors as well as their categories.

Figure 3 shows a visual summary of the questionnaire results. Notice that the dimensions C1 (cultural) and C4 (measurement) show the largest numbers of positive answers, meaning that these are considered to be the most influential dimensions for the success of CE practices. Similarly, dimensions C2 (automation) and C3 (sharing) show the largest numbers of negative answers, meaning that these are considered to be the less influential dimensions for the success of CE practices. A more detailed analysis of the results is provided in Table 2.

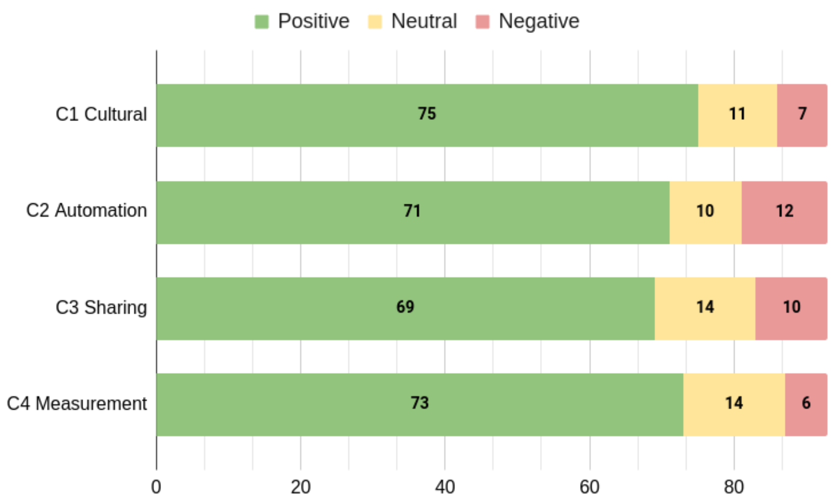

Figure 3. Visual summary of the questionnaire results.

As expected, all the identified success factors positively impact the implementation of IT resources in the CE environment (Table 2). The results show that SF16 (smart product for data collection) is considered by 85% of the responses as a positively related factor. Meanwhile, SF07 (sustainable technological infrastructure Development) is considered the second most related factor for implementing IT resources in CE paradigm. The third highest considered factor is SF03 (designing an enterprise's IT architecture in compatibility with cloud services).

The results indicate that SF06 (lean production or circular design) is marked with the highest disagreements of being positively related to the implementation of IT in the CE. Thus, 16% of the responses disagreed with this factor effect. The second highest negatively ranked factors are SF08 (information safety and security ethics), SF14 (product design using AI), and SF15 (setup effective monitoring system to gauge current performance against developed KPIs). Despite their rank and the disagreement with their impact, they are considered success factors by other experts.

The key categories of success factors scored C1 (culture, 81%), C2 (automation, 76%), C3 (sharing, 74%) and C4 (measurement, 78%), and this renders that experts strongly agree that key categories of the success factors are important for the execution of CE practices using IT resources. From these results, it is noticed that there is an agreement that the shift toward CE requires a foundation. However, some disagreement is faced regarding the ranking of the individual factors with respect to their impact on building this foundation required for this shift and transition.

Table 2. Questionnaire summarized results, where SA, A, N, D, and SD refers to strongly agree, agree, neutral, disagree, and strongly disagree, respectively.

No	Success Factors and Categories	Number of Responses (N = 93)							
		Positive			Neutral		Negative		
		SA	A	%	N	%	D	SD	%
C1	Cultural	24	51	81	11	12	1	6	8
SF01	Effective Strategy Formulation by Correspondence among IT and CE Practitioners	26	43	74	12	13	4	8	13
SF02	Developing Economic Policies/Agendas in Support of CE Activities	29	38	72	14	15	3	9	13
SF03	Designing an Enterprise's IT Architecture in Compatibility with Cloud Services	24	50	80	9	10	2	8	11
SF04	Formalize Relationship between Decision Makers Worldwide	27	40	72	14	15	3	9	13
SF05	Machine-to-Machine Communication Ethics	31	39	75	12	13	4	7	12
C2	Automation	31	40	76	10	11	4	8	13
SF06	Lean Production or Circular Design Strategies	23	40	68	15	16	4	11	16
SF07	Sustainable Technological Infrastructure Development	30	48	84	7	8	1	7	9
SF08	Information Safety and Security Ethics	26	38	69	16	17	6	7	14
SF09	Reverse Logistics	27	38	70	16	17	5	7	13
C3	Sharing	29	40	74	14	15	4	6	11
SF10	Top Management Commitment	30	40	75	12	13	3	8	12
SF11	Product Service System	30	38	73	14	15	5	6	12
SF12	Industrial Symbiosis	26	44	75	13	14	3	7	11
C4	Measurement	39	34	78	14	15	2	4	6
SF13	Develop Organizational Goals in Coordination with CE by Focusing on Process Automation	27	40	72	15	16	5	6	12
SF14	Product Design using AI	30	38	73	12	13	5	8	14
SF15	Setup Effective Monitoring System to Gauge Current Performance against Developed KPIs	27	43	75	10	11	6	7	14
SF16	Smart Product for Data Collection	33	46	85	5	5	4	5	10

Referring the SDGs, these defined success factors are making a significant contribution to achieving the accelerated transition toward circular economy and sustainability using information technology resources (Figure 4). It implies that utilizing Industry 4.0 has a positive impact on the economic performance of an organization at a global level when explored in terms of the CE perspective.

In a world where we all look toward technology to achieve sustainability goals, we cannot forget to mention that technology also has a massive carbon footprint that can worsen the situation instead of achieving the opposite. Data centers around the world take up 1% of energy demand in 2019 and will be increased by 3% in the coming years Microsoft has declared to use 100% renewable energy by 2025 and Google by 2030 [67]. That is where awareness of corporate sustainability and 'collective action' comes into play, as the CO_2 emissions from technological resources can be controlled with behavior modification by building a community of responsible leaders and setting policies at the global and corporate levels. Albareda and Sison [68] discussed the impacts of commons organizing in terms of ethics in economics, and Filatova et al. [69] scientifically demonstrated behavioral changes and conformity through agent-based modeling that was explored in terms of feedback among environment and their social agents. Ostrom [70] discussed the study of collective action in institutional economics which highlights the fact that policymakers and corporate responsibility begin with every single one of us.

An example of digital footprint is shown in a BCC report (https://www.bbc.com/news/technology-45745362 (accessed on 31 October 2022)). The report states that video streaming also has a massive carbon footprint, i.e., 300 million tonnes (1% of global emissions), which can be controlled by using low-resolution settings on our devices. Thus, adjusting our lifestyles can save our environment. These issues associated with technology impacting our environment can be tackled through collective actions and common organizing since it is the responsibility of individuals, corporate enterprises and policymakers. All eyes are on the technology industry to solve the climate crises which give rise to the field of sustainable IT, and the paper studies sustainable production from the design phase to end-of-life activities in an effort to combat the environmental issues at hand.

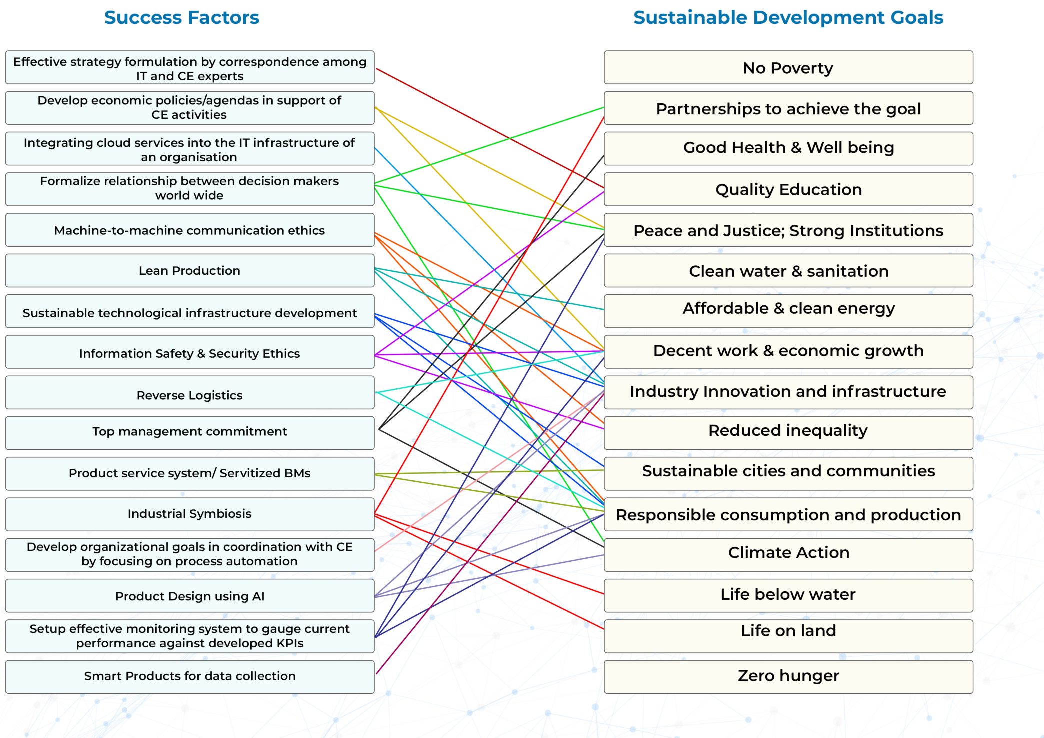

Figure 4. The relation between success factors and SDGs.

10. Conclusions

In today's progressive era, the economy is shifting from linear to circular. With advancements in IT, technology can play an extremely vital role in executing circularity-based models. Therefore, considering the importance of information technology resources in the circular economy, we are motivated to explore the factors that could positively influence the execution of the circular economy using information technology resources. Sixteen factors were identified. All the identified factors influence the application of IT in the circular economy. However, it was shown that there is a significant difference in their allocation of importance with respect to different practitioners.

The development of the IT infrastructure enables the industry to reduce manufacturing costs, enhances the quality of logistics services and ensures the efficient utilization of energy and other resources. It intensifies the economic competitiveness levels by highlighting the opportunities for developing novel business models, such as servitization, and strategies by deploying innovative technologies for planning and managing business processes across the entire value chain, thereby creating new jobs and industries—i.e., for reverse logistics industrial symbiosis. Industry 4.0 was initially viewed as a concept that massively modifies manufacturing procedures, but its implications spread over a wide range of human activities, including manufacturing, trade, health, agriculture, and logistics.

The transition toward CE is not a slight change that can be achieved using IT or by taking a linear model and adding a few processes to introduce circularity. This transition is a fundamental shift in the way we think, behave, own, consume and waste. Every company and individual can reshape their business or consumption model that will help the community as a whole, thus reducing land, air and water pollution and natural resource extraction. Hence, knowing the success factors and proposing how to implement those will not suffice for this massive shift. Challenges of the process need to be thoroughly investigated as the next step. Some of the challenges mentioned in the literature are consumer behavior, business attitude, economic costs, corporate responsibility, lack of capacity, and data uncertainty. Addressing these changes will bring about societal cooperation and turn the shareholder economy into a stakeholder economy with collective actions.

Our study is limited to analyzing the factors that affect the implementation of circular economy in a production and manufacturing sector. Thus, other sectors are excluded from this study, such as service, health, and agricultural sectors. Excluded sectors from this study might share some of the defined success factors and have their own factors. In addition, the ranking of these factors could vary among these sectors. These factors and their influence should be examined and studied.

As future research lines, we plan to investigate how CE practice are being implemented in different regions of the world, and to analyze if there are significant differences among the implementation speeds and social awareness depending on the considered region.

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