Chapter

An Innovative Visualization Tool to Boost and Monitor Circular Economy: An Overview of Its Applications at Different Industrial Sectors

Augusto Bianchini and Jessica Rossi

Abstract

The quantification of the circular economy and sustainability is a relevant aspect at different levels of applications: (i) the companies need to evaluate and improve the environmental, economic, and social impacts of their products and processes; (ii) the financial bodies must have quantitative information about the potential and risks of different proposed initiatives to select the optimal opportunity; and (iii) the policy-makers must be guided for the coherent definition of strategies at regional, national and international scales, setting realistic targets and measuring their effectiveness. However, the lack of comprehensive and robust approaches to quantify circular economy makes it challenging to apply quantitative methods and indicators in different contexts and compare the results, with the risk of limiting the practical implementation of circular initiatives due to unknown and/or unclear potential and contribution. The ViVACE® tool (Visualization of Value to Assess Circular Economy), developed by the authors, is a promising and effective means to collect data in a systematized manner, helpful to assess sectorial and cross-sectorial indicators about sustainability. It has been applied to different industrial sectors (e.g., plastics, food processing, textile) for different purposes. These applications are described in detail to highlight the potential, versatility, and implications of the proposed tool in boosting the effective transition to a circular economy.

Keywords: circular economy, sustainability, indicators, performance measures

1. Introduction

Several definitions of circular economy (CE) exist in the literature, mainly focusing on different aspects of its core concept, firstly defined in the 1970s and then developed over time among different schools of thought [1–3]. The European Commission has delineated a simple but complete definition of CE in 2015, which specifies that [4]:

> *"In a circular economy, the value of products and materials is maintained for as long as possible. Waste and resource use are minimized, and when a product reaches the end of its life, it is used again to create further value."*

In the last two decades, CE has gained great attention and commitment from international governments, policy makers, and institutions. They identified in this economic model a great opportunity to: (i) build long-term resilience and sustainability, (ii) determine business and economic competitiveness, and (iii) provide societal and environmental benefits [5, 6]. In 2020, the European Commission launched "A new Circular Economy Action Plan for a cleaner and more competitive Europe" [7], which states that going mainstream the CE will significantly contribute to the achievement of a climate-neutral society and economy, according to the European Green Deal objective [8]. In [9], the benefits and contribution of CE on the pillars of sustainability have been deeply analyzed, highlighting how CE directly or indirectly addresses the achievement of a relevant number of the 17 Sustainable Development Goals (SDGs) targets, described in the United Nation Agenda 2030 to attain sustainable development in a balanced manner considering the interrelated and holistic nature of the environmental, social and economic dimensions of sustainability.

Since each business model is, by definition, focused on creating and capture value, generating sustainable and competitive advantages through product and process innovation, the enterprises have a fundamental and active role in the transition to a CE, which guides the innovation to transform the way products are designed, manufactured and used along their entire life-cycle [10, 11]. To enable an effective and successful circular strategy in the industrial sector, all actors in the supply chain should take part in the transition [12]. In [13], a literature review on the practical application of CE in the manufacturing industry is provided: even if empirical case studies, focusing on applications for narrowing and closing the resource loops, increase over time, it has been highlighted that the implementation of CE in the manufacturing sector is still sporadic and it is not possible to find in literature any kind of systematized recommendations able to guide companies in the successful CE transition of their business models. To overcome the lacking of comprehensive analyses to identify the most impactful CE actions on a specific business model building block, the reference [14] provides a list of nine general managerial insights to support companies in shifting to the practical implementation of CE in their business models.

Several studies are focused on the identification of the main barriers to the design and implementation of successful CE strategies [15–17]. One of the most recognized limits for the overcoming of the CE practice-theory gap is the lack of clear and consistent methods to actually assess the circularity and sustainability of products, processes, business models, and strategies. The quantification of the achieved circularity level involves different scales, from the micro/meso scale (companies, supply chains, industrial parks, etc.) to the macro scale (cities, regions, countries, etc.). At a company level, quantitative information is fundamental to rapidly and effectively make decisions about innovations and investments [18]. The importance of assessing initiatives and practices is greater in the CE context, which is by nature characterized by a network of interconnected companies; consequently, a holistic and transparent method to measure the impact of CE becomes fundamental [19]. At macro-level, the primary need for policy- and decision-makers is a coherent definition of strategical visions at regional, national and international levels, setting realistic targets and measuring their effectiveness [20, 21].

Several approaches and indicators to measure circularity have emerged in the last years. Numerous recent studies reviewed the existing literature about circular indicators and metrics, dividing them according to the system level (micro, meso, macro) and, within each level, according to the sustainability pillars that they assess (environmental, economic, and social) [19, 22–24]. These papers highlight that hundreds of indicators to assess CE exist, but there are still two main issues for their widespread implementation, ensuring a suitable CE assessment. (i) The first issue comes to the assessment of CE within the same scale/level. In particular, high diversity and fragmentation of approaches and metrics have been identified, making it difficult to compare the industrial applications in which such indicators and methods are used [19, 23]. The causes of this fragmentation are mainly two. The first element is related to the big concept of the CE umbrella: hundreds of CE definitions exist, and its paradigm is developing without an overall consensus regarding circular actions and aspects [25]. This diversity in the theoretical background is reflected in the industrial adoption of CE, which provides very specific case studies. Consequently, these peculiarities also require a tailored assessment framework, challenging to be replicated in other contexts. The second element that determines fragmentation in CE assessment at the same scale is linked to the lack of standards. In fact, only practical but not official guidance on CE principles, practices, and monitoring have been published. Only the British Standards Institution launched a new standard about CE, the "BS 8001:2017 – Framework for implementing the principles of the circular economy in organizations—Guide" [26], but international standardized guidelines, and their transposition at a national level, are still under development and are not expected before 2022. (ii) The second issue recognized in literature in the use of circular indicators consists of the connection among system levels, allowing the identification of the links between the micro- and macro- level metrics [22].

Often, in the literature reviews about available circular indicators [19, 22, 27], a significant statement about the difficulties and complexity to use and implement these metrics is highlighted and refers to the relevant need to collect and process a large quantity of data (typically related to aspects not yet monitored in the industry), characterized by suitable robustness and consistency. To overcome this barrier, the authors developed an innovative visualization tool ViVACE® (Visualization of Value to Assess Circular Economy), published in 2019 [28] and registered as a mark in 2020, able to intuitively provide quantitative information about CE to guide the decision-making process and monitor the impacts at the described scales. Starting from the question of why such a recognized and consolidated concept was so difficult to put in practice, an analysis of the existing visualization tools to explain the CE paradigm was conducted (considering both grey and scientific literature) to select the most suitable to boost an effective and successful transition to a more sustainable production and consumption model. This analysis highlighted the lack of three main features, without which the demonstration of the benefits and limits to shift to a CE should be challenging, above all for practitioners. These missing characteristics in the available tools are: (i) the capacity to provide quantitative information about circularity; (ii) the possibility to be adapted to different industrial sectors; and (iii) having correspondence to what effectively occurs in real industrial contexts. From this framework, the development of a new visualization tool started.

After a little more than a year from the building of the tool, the authors applied it to different industrial sectors, confirming its features and capacity to boost the practical implementation of CE and to feed suitable and significant indicators to assess practice performance. The chapter aims to present an overview of the application fields of the ViVACE® tool, highlighting its main advantages, possible improvements, and the main implications to reach the purposes of different levels in the CE field. After this first introduction, which aims to introduce the most challenging aspects in quantifying to a CE, limiting its practical transition, the remaining parts of the chapter are structured in the other three sections. Section 2 presents the methodological approach adopted by the authors to boost an effective shift to a CE through the adoption of the innovative tool ViVACE® able to provide useful quantitative information. In particular, this Section describes the main implemented/ongoing applications of the tool in different industrial sectors, according to several purposes. Section 3 analyses and categorizes the previously described applications to demonstrate the potential of the tool in terms of coverage of, e.g., different sectors, actions within the CE umbrella concept, and scales. This standardization supports an easy replication of the tool in other contexts and upscaling according to different implications. Finally, Section 4 describes the main conclusions, recapping the contribution that the wide use of the proposed tool could provide for the identification and measurement of unexplored circular initiatives through a quantitative demonstration of their effectiveness.

2. Application of ViVACE® to different industrial sectors and circular initiatives

The general elements that compose ViVACE® and the methods used to build it are deeply described in [28]. **Figure 1** shows a generic "stage" of the tool, representing the material flows in a company or a part of a specific industrial process (the graphical

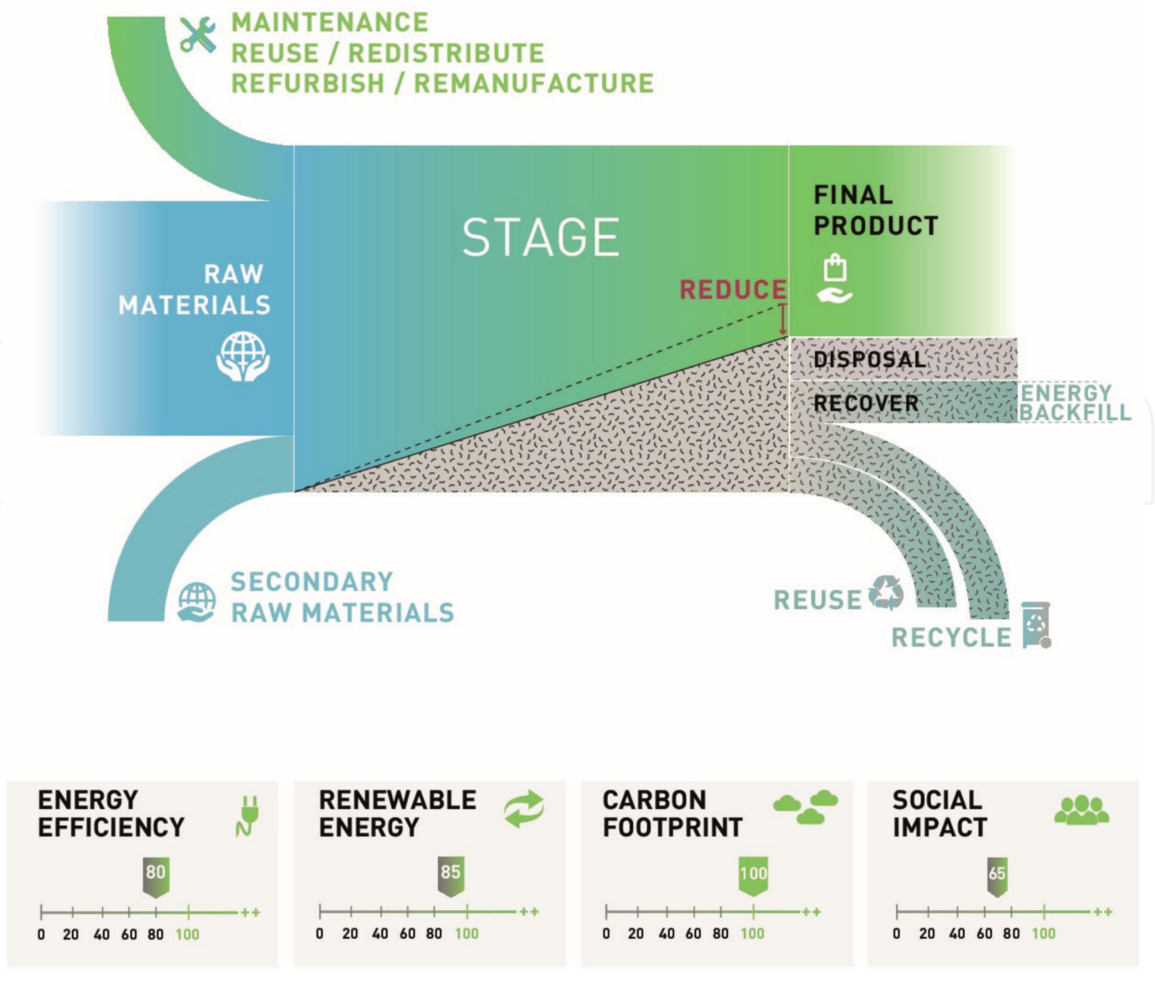

Figure 1.
Representation of a generic stage according to ViVACE® tool [28].

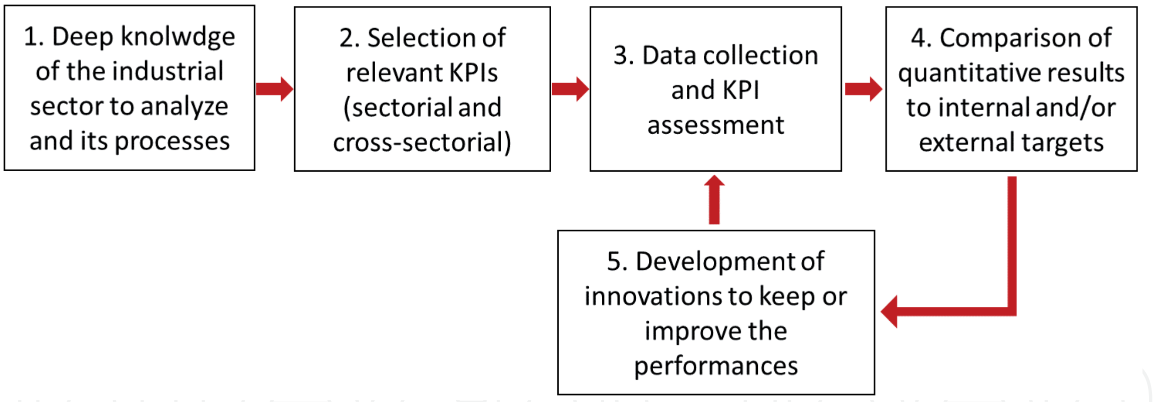

Figure 2.
Methodological steps, based on ViVACE® tool, to support the transition to a CE.

width is proportional to the actual flow) and completed with the measurement of some transversal KPIs.

The tool was already used to analyze circular case studies available in the literature, with the aim to show its potential and versatility [29]. The lack of accessible and quantitative information limits the application of the ViVACE® tool, which has been only qualitatively set. However, without a quantitative analysis of those case studies, for example, with the use of relevant KPIs, it is not possible to compare the improvements generated by the "linear" scenario or by different circular opportunities.

On the contrary, the authors' approach is based on the quantification ensured by the use of ViVACE® tool. In particular, the typical methodology used to address and support an effective transition to a CE is based on the steps shown in **Figure 2**. These methodological steps have already been implemented in different industrial contexts, providing interesting results.

This Section describes the application fields in which the ViVACE® tool has been implemented. For each application, which varies a lot for sector and type of action, the context is described, highlighting the barriers and some limiting aspects for the development of circular actions. Moreover, the implementation of ViVACE® tool and its main results are reported to understand its contribution in accelerating the transition to a CE in the considered sectors.

2.1 Phosphorus management

Phosphorus (P) is a main raw material for fertilizer production: with its irreplaceable properties, it ensures proper plant growth, providing food directly for human consumption or for animal growth, becoming human food in a second term. It derives that P represents a crucial building block for food security. Due to its importance, but also its crucial issues, P is listed as a critical raw material for the EU economy [30]. The criticality is given by two main priority aspects to be considered for P management in Europe: P is a non-renewable resource since a time misbalance exists between P geological cycle (million years) and the anthropic use cycle (daily-annual); moreover, primary P mines are concentrated in few areas (China, Morocco, USA), mostly not belonging to EU, which imports more than 90% of its P demand [31, 32]. For these reasons, the sustainable use of nutrients, including P, is a priority for the recent EU strategies [7, 8].

On the other hand, along the anthropic use cycle, P is used with very low efficiency since there are P losses at every step of its life cycle, but it remains available in certain waste flows, from which it can be recovered and reused, according to the CE paradigm. Along the food value chain, there are three main waste flows characterized by high concentrations of P: animal manure, urban wastewater, and sewage sludge, and food processing waste flows, such as slaughters, other solid waste, and wastewater [33]. More than 30 technological processes, some of them commercially viable, have been already developed to recover P from several types of waste flows (e.g., wastewater, sludge, and ashes) in different forms (e.g., struvite, calcium phosphate) [34]. Although many opportunities for P recovery and reuse are available at the industrial level, the full-scale implementation of these technologies is still limited. Moreover, the presence of P in certain industrial waste flows is often perceived as an issue than an opportunity [35].

The EU project Prosumer, funded by EIT Climate KIC (2020) and coordinated by the authors, tackled the question about what elements are missing and necessary to unlock a wide diffusion of P recovery technologies at the industrial level. It emerged that the companies have not suitable tools and methods to transfer the interdisciplinary know-how developed by the scientific community in their contexts, translating it into quantitative information to support their decision-making process about P recovery. Consequently, within the project Prosumer, the authors provided an industry-oriented methodology, consisting of four main steps, to guide the companies in the identification of the most suitable P management pathway, according to their interests and business strategies. In this methodology, the ViVACE® tool has a fundamental role in providing structured data about P flows along with the industrial processes and in the waste streams, becoming useful inputs for other tools to evaluate the economic feasibility of potential investments in P recovery and other relevant KPIs. The Prosumer methodology and its application to an Italian food company are well described in [36]. **Figure 3** shows the setting of the ViVACE® tool representative of the annual quantity of P contained in the material flows both in the food processing and wastewater treatment plant. In this first application, it is shown the "first draft" of the tool, set with common software and manually, that means without using the official graphics, as in the following applications, with the aim to understand how it can be constructed. To fill the visualization tool, the annual quantities of P were evaluated, considering as stages different steps within the food processing and the wastewater treatment and analyzing the inputs and outputs of P contained in several flows (raw materials and other ingredients, final products, solid waste, wastewater, sewage sludge, etc.) within the boundaries of the company. The annual P flows (kg/year) were reported as a proportion of the maximum value that corresponds to the quantity of P that enters the food processing.

The setting of the ViVACE® tool allowed the evaluation of significant KPIs to measure the process and highlighted potential opportunities to manage P according to a CE. **Table 1** summarizes the relevant environmental and economic KPIs obtained from the application.

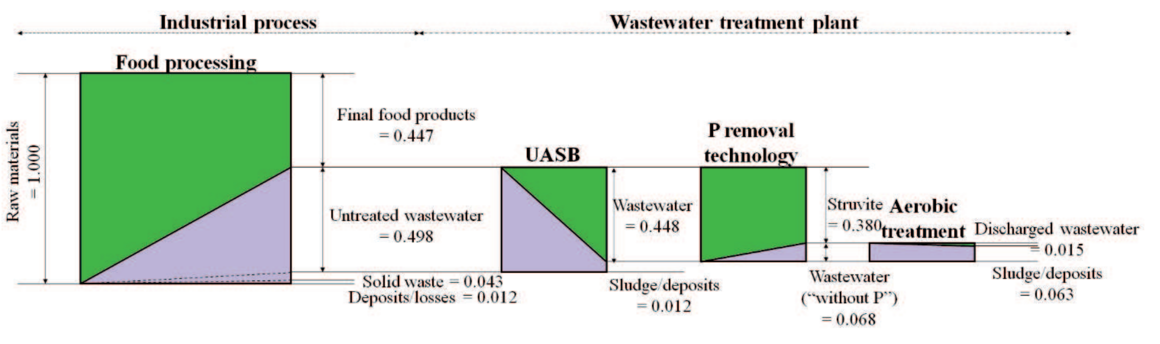

Figure 3.
Normalized annual P flows in the food company analyzed in the project Prosumer through ViVACE® tool [36].

Typology	KPI	Description	Value
Environmental	Final P concentration	P concentration in the discharged wastewater to be compared with the legislative limits.	6.6 mg/l
	P removal efficiency	It represents the efficiency of the entire wastewater treatment plant (WWTP).	96.9%
	P recovery technology efficiency	It depends on the technology and the operating parameters in the specific process.	80.1%
	P use efficiency	It represents the part of P that effectively remains in final products, comparing it to the P quantity that enters in the process.	44.7%
	P load coefficient	It represents the "impact" of final products in terms of final emissions of P in wastewater.	34.4 mg P/kg
	Unrecovered P	It represents the unrecoverable part of P, dispersed along the entire process.	13.6%
Economic	Specific costs per amount of recovered P	It represents the costs necessary to remove/recovery 1 kg of P with specific technology and plant.	0.864 €/kg P
	Incidence of P removal cost	It compares the cost incidence of P removal on the wastewater disposal.	5.39%

Table 1.
KPIs used to assess the sustainability of P removal/recycling from wastewater.

According to the economic feasibility study, fed by the collected quantitative data about P flows, it derived that, although the cost for P recovery covers a minor part of the wastewater disposal costs, the price for the selling of the recovered P, to make the investment sustainable, is greater than the cost of primary P rocks. This and other barriers to effectively shift to a more sustainable P management must still be addressed, as analyzed by recent studies [34, 35]. Nevertheless, with the applied methodology, the companies can have all the quantitative information to unlock, at least, an interest in evaluating and exploiting the opportunity to recover P from their waste.

2.2 Plastics sector

Plastic has been identified as a priority area in the new European CE Action Plan [7] due to its high complexity in the management of its waste and its negative impact if it improperly reaches the environment. Although its irreplaceable features, such as ease of processing, low weight and cost, and hygiene, the typical linear management of this material is no longer sustainable, above all when it is used for applications characterized by a very short service life, for example, the single-use plastics and the packaging. These specific functions are affected by a high production of waste, characterized by a low recycling rate in comparison to other materials (e.g., paper, metals, glass).

There are two major aspects that affect and limit a greater recycling rate for plastics. The first issue is related to the wide variety of polymers included in the typical waste flow to be managed. The second limiting aspect is linked to the downgrading of recycled plastic properties. Plastic waste flows containing only one type of polymer are quite easy to recycle. Every recycling process is studied and implemented to work with a specific polymer as an input material. In case the input

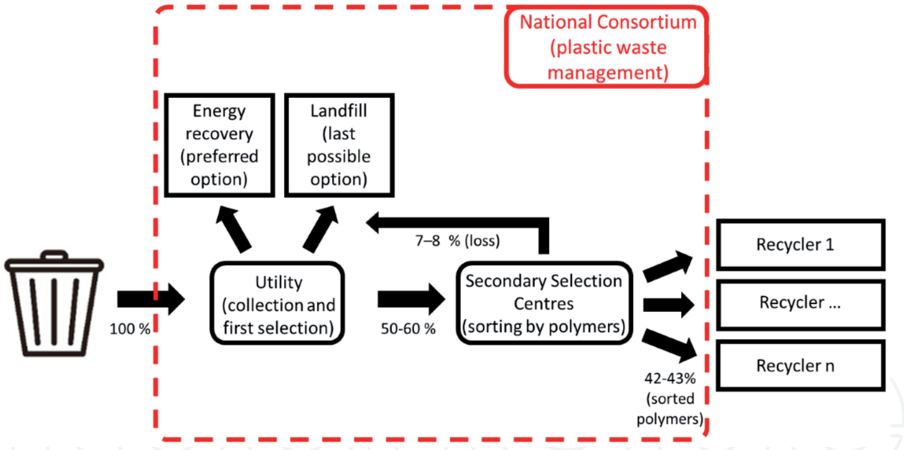

Figure 4.
Current Italian plastic waste management system and share of the main material flows.

flow is not contaminated by other types of polymer, the recycled plastics has good properties, even if a certain grade of degradation occurs.

In this scenario, the current Italian plastic waste management system is characterized by the described two critical issues. A national consortium, created to optimize the collection, recovery, and recycling of plastic packaging, manages the entire plastic waste system. It provides indications for different actors to manage several activities in the waste management process [37]. The territorial utility is the only one that can collect and carry plastic materials from urban and industrial waste. The utility does a first sorting phase from the plastic bin, sending the suitable materials (mainly packaging) to the following stages (50–60% of the entire flow). The remaining part, consisting of non-recyclable plastics, is sent to energy recovery (preferred option) or landfill (last option), according to the national consortium indications [38]. The flow selected for recycling is sent to a secondary selection center that has the technology to sort materials by polymer and by color. In this phase, another part of plastics waste (about 7–8%) is lost due to the sorting system inefficiency [39]. It derives that only 42–43% of the total amount of material collected in the urban plastic bin is sold to recyclers. Not all of this quantity is effectively recycled due to another inefficiency in the recycling process, which depends on the technological development of the specific plant. **Figure 4** shows the schematic view of the Italian plastic waste management system.

The current trend to eliminate the problems of plastics management is to shift to a "plastic free" model. However, for some applications, the replacement of plastics with other materials may not be the most sustainable solution, at least in the short term, considering environmental or economic aspects, or both of them [40]. A more promising solution, above all in the short term, could be shifting to an effective CE for plastics, capturing the maximum value of the resource through improved after-use plastic management [41]. With the aim to increase the collection, sorting, and recycling efficiency of the current waste management system, to minimize waste generation and resource use according to the CE paradigm, the authors' team designed, implemented, and assessed two innovative circular initiatives for plastics, one applied to sports events (named #CORRIPULITO) and the second applied to the food value chain (named RICIRCOLA – Plastic Waste Free).

2.2.1 #CORRIPULITO: a sustainable model to manage plastic waste at sport events

The organization of sports events can generate both positive and negative effects on the host territory. A high amount of waste generated during these events, if not properly managed, can determine a negative environmental impact, above all plastics waste [42]. To reduce the environmental impact of sports events, the #CORRIPULITO initiative was designed and implemented in a small marathon to improve the management of plastic waste in comparison to the previous editions of the same event. In this specific context, four types of plastics were sorted and collected to increase the recovery efficiency of the management system, activating dedicated reverse logistics. A detailed description of the design and implementation of #CORRIPULITO is in [43].

The implementation of the ViVACE® tool allowed the assessment of the sustainability of the initiative, and particularly of the environmental and economic pillars, through the collection of useful and systematized data and their elaboration to evaluate significant KPIs. Also, the detailed steps for the implementation of the

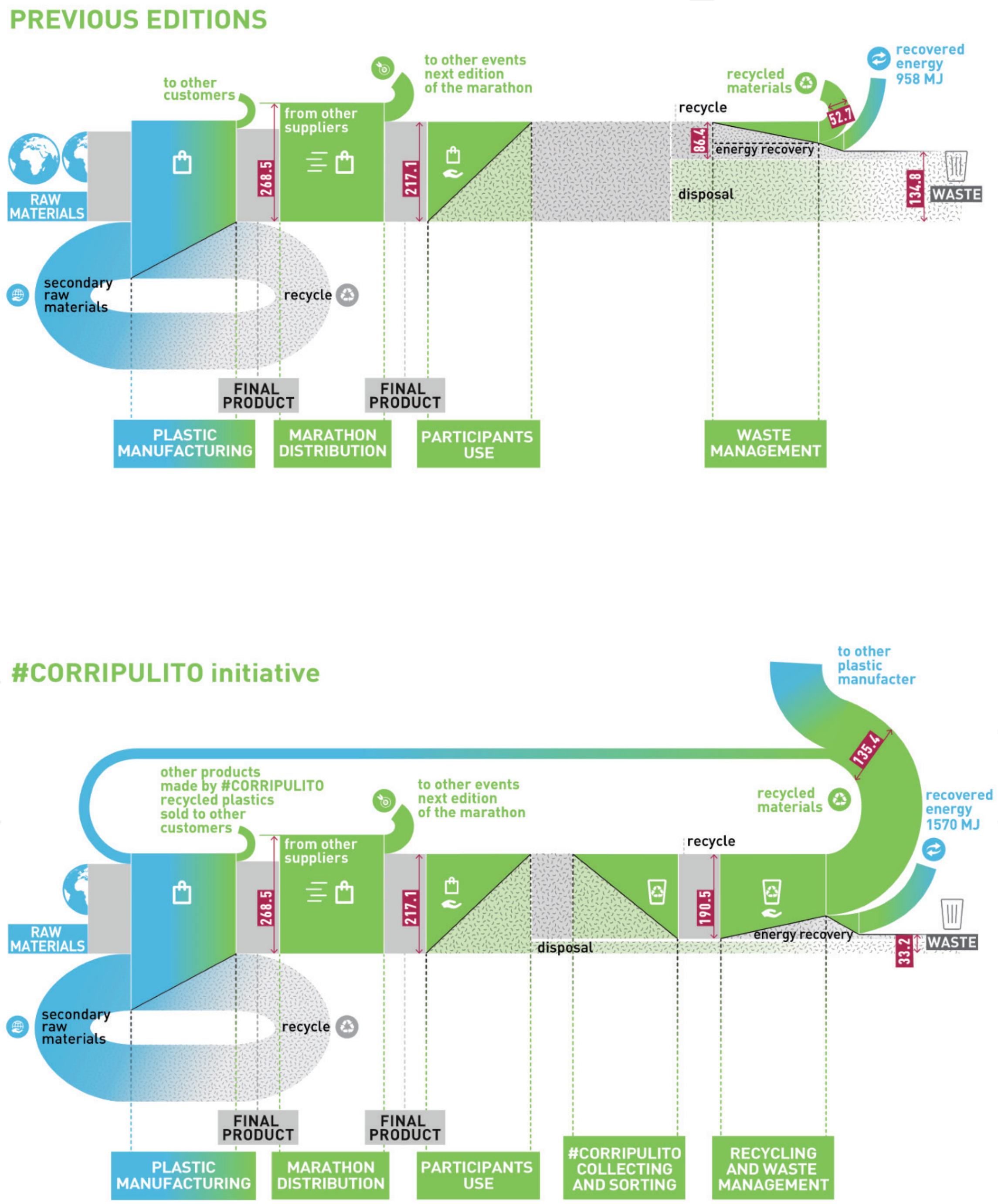

Figure 5.
Setting of the ViVACE® tool for the #CORRIPULITO initiative and its comparison to the previous editions of the sport event [43].

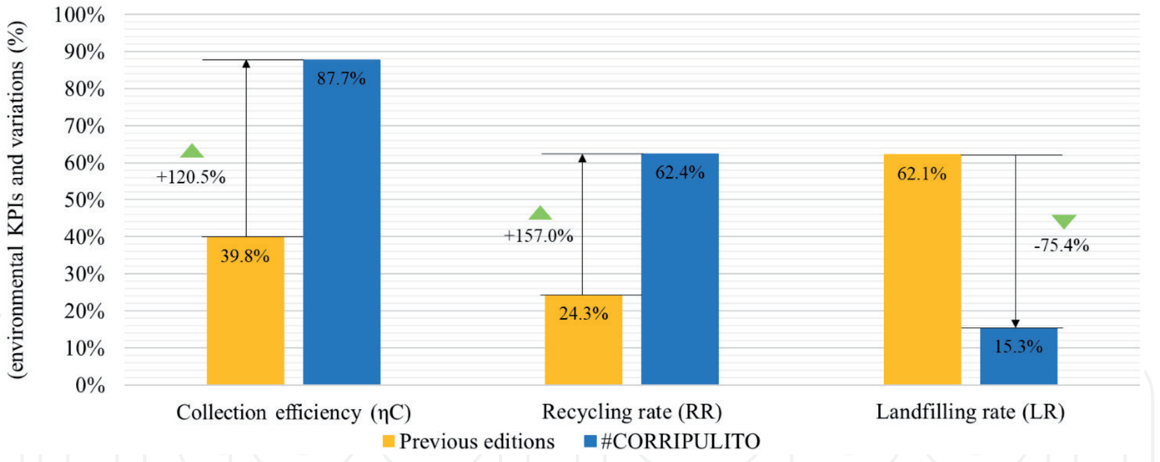

Figure 6.
Evaluation of environmental KPIs representative of plastic waste management [43].

ViVACE® tool to #CORRIPULITO are provided in [43]. **Figures 5** and **6** show the main quantitative results of the sustainability assessment, respectively as the setting of the visualization tool and evaluation of the selected environmental KPIs, comparing two scenarios (previous editions of the considered sport event and #CORRIPULITO).

2.2.2 RICIRCOLA: plastic waste free - an innovative management model for plastic food packaging

Among plastic materials, PET (polyethylene terephthalate) has become the most promising packaging material for food products, and above all for beverages, due to its excellent features, such as high clarity and good barrier properties towards moisture and oxygen, and also for its high potential for reuse after recycling process also for food contact applications [44, 45]. Currently, PET bottles, collected and send to the recycling process, are more than 50% of the consumed bottles, which is a very high rate in comparison to other disposed plastics. Bottles are not the only packaging in PET. PET trays (about 1/3 than PET bottle consumption, by weight – PETcore data) are widespread in food packaging applications, as they preserve and keep food fresh longer. PET trays contain almost 50% rPET, but they are typically separated from bottle flow and are very difficult to be recycled to a third life [46]. The consequence is a great loss of PET tray value after the food consumption phase.

With the aim to recover the value of plastic food trays, a new model for the management of plastic packaging in the food supply chain is proposed, based on the concepts of CE. The main idea at the basis of the new model, called "RICIRCOLA - Plastic Waste Free" is represented in **Figure 7**. It consists of the design of innovative plastic packaging, made with a mono-polymer (PET), having specific characteristics that allow: (i) the complete traceability from production to post-consumption phase through the insertion of a specific tracking element, particularly an RFID tag; (ii) the increase of collection and sorting efficiency through the involvement of the consumer who receives a fee if he brings back the after-use packaging at the collecting station, set up at the retailer; (iii) a simplified reverse logistics, ensured through the dedicated collection and sorting system that allows a single-polymer waste flow, with the aim to facilitate the recycling at the end-of-life, enlarging the applications of the recycled plastics. To assure all these features, an integrated value chain that comprises packaging the manufacturer, food brand owners, retailer, consumers, and the plastic recycler, was established, following a life-cycle thinking approach.

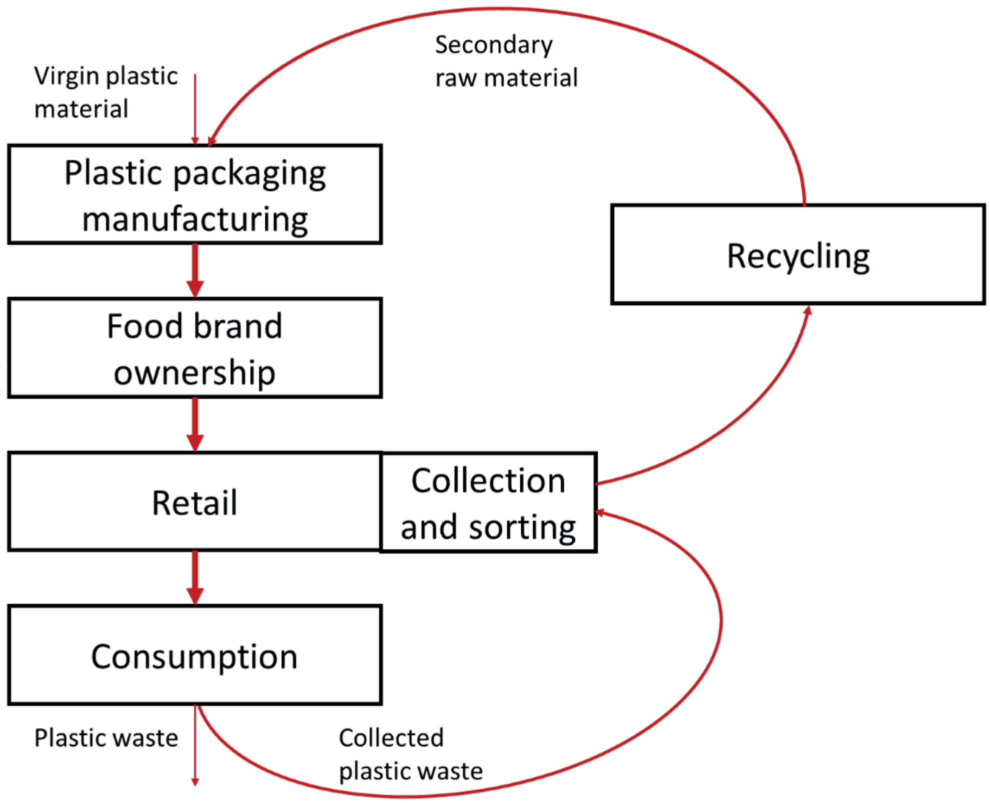

Figure 7.
Schematic framework of the novel management system for plastic packaging.

The proposed model was tested and validated in Emilia-Romagna (Italy) for two months (October–November 2020), redesigning the packaging for two food products distributed in three supermarkets, ensuring a fee of 0.20 €/tray for the engaged consumer. The collected plastics were sent to the recycler to manufacture other food trays.

Figure 8 shows the final set of the ViVACE® tool comparing three different scenarios: (i) the current management system of trays in Italy, (ii) the results obtained with the initiative "RICIRCOLA – Plastic Waste Free" after two months of experimentation, and (iii) the projection of the results after a year of implementation of the proposed model. The detailed description of the model and its results, assessed with the use of ViVACE®, is out of the scope of this chapter and is the subject of a dedicated paper under submission. However, it is possible to extract some relevant and macro quantitative information to compare the "RICIRCOLA - Plastic Waste Free" model to the current Italian waste management system. The results highlight that, in comparison to the current situation, considering the same quantity of collected plastics after the consumption phase, the innovative model "RICIRCOLA - Plastic Waste" should increase the plastic waste recovery efficiency of about +120%. The projection of the results achieved during the experimentation, after one year of practice, demonstrates that it could be possible to increase the recycled plastic quantity by about +126%, reduce the waste sent to landfill (−57%) and replace the 36% of virgin plastics with secondary raw materials. It derives that this novel model can really contribute to the achievement of the target for plastic recycling (55%), set by the European Strategy for plastics in 2030.

2.3 Textile/footwear sector

Due to the current production, distribution, and consumption system, the fashion sector is one of the most impactful since it is still completely based on a linear

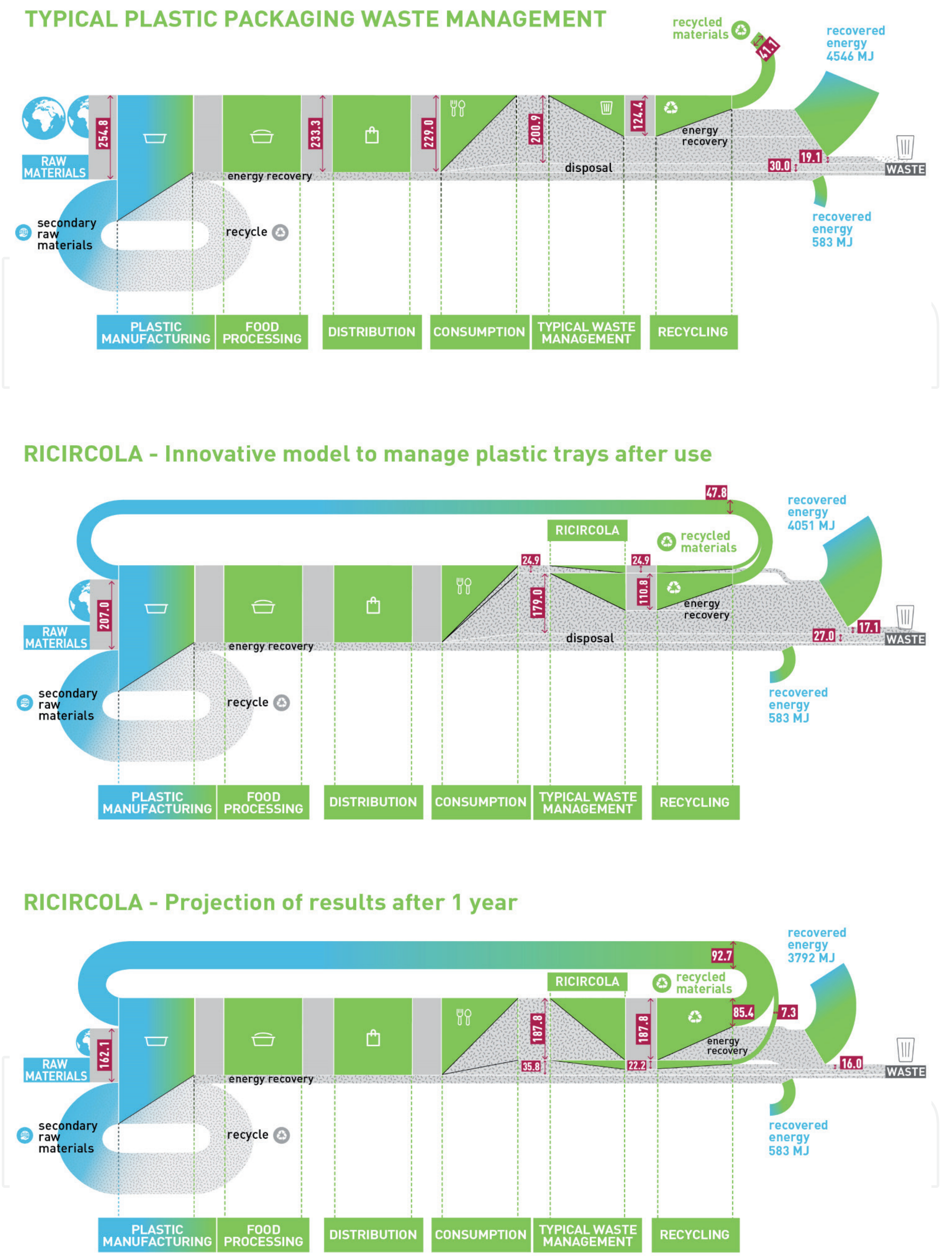

Figure 8.
Setting of the ViVACE® tool for the "RICIRCOLA – Plastic Waste free" in three scenarios: current situation, experimentation, projection after one year.

economy, generating a high amount of waste and high level of pollution for the manufacturing of products often characterized by a short life (due to the seasonality of materials and components linked to sudden changes in fashion trends) and difficult to be recovered [47]. Due to its negative environmental impacts, textiles are one of the priority areas of the new EU Circular Economy Action Plan [7]. In particular, some of the environmental issues generated by the textile/footwear sector are related to climate change and large use of non-renewable resources during production, and water pollution and the release of hazardous agents (e.g., microplastics) both in the manufacturing and using phases, problems that become more complex due to the underutilization and the low reuse and recycling rate of fashion products [48]. Moreover, the fashion industry is strongly affected by issues and potential failures related to reputation, above all in the luxury fashion industry of for very famous brands: poor labor conditions, chemical contamination of soil and water, workers' exposure to chemicals, and animal cruelty are some of the main problems perceived as unethical, which can change the external perception of the brand and its products [49].

The transition to a CE can really improve the current fashion sector, addressing both the macro-issues, which are the increase in resource efficiency and the reduction of the negative environmental impacts, and reducing the risk of reputation problems, through a specific feature of this sustainable economic paradigm, which is the traceability of the materials, ensured by digitalization [3, 15, 49]. However, there are some challenging aspects that limit this change.

(i) The fashion value chain is characterized by high fragmentation and the involvement of very different actors. Most of the companies involved in the fashion value chain are SMEs (small-medium enterprises) with an organizational fragility that does not prevent their operations at high-quality levels, but that limits their potential for growth in terms of product development and presence on the market. The figure is reflected in the difficulty of some companies to proactively face up to extremely topical issues, and the lack of digitization of resources which prevents the importance of issues such as waste reduction, chemical risk, transition to renewable energy, changing climate, and ecological handling. (ii) Fashion production, which has always been growing in recent years, has not been accompanied by innovative industrial policies, with a process that has always remained the same over the last decades, limiting the inclusion of innovations based on sustainability and circularity on products and processes [50, 51].

The lack of traceability and transparency in information about resource use determines these aspects [52]. The ViVACE® tool has been proposed to provide a snapshot of the current fashion supply chain, in the footwear district in Emilia-Romagna Region, with the aim to collect quantitative information about sustainability (environmental, economic, and social). The starting point for this application has been the analysis of the footwear assembler, the last manufacturing stage of this supply chain. Unlike previously described applications of the ViVACE® tool, in this case, the method has been implemented not to a single resource (see the P case study) or to products (see applications in plastics sector), but to entire assembling process, considering all the materials and other resources (e.g., energy, waste, water, logistics equipment, and transports) necessary for the final products. The main result of this application is a dashboard, fed by relevant KPIs about the process, able to guide the managers of the single operational units to monitor their performance. The preliminary application of the ViVACE® tool and the evaluation of relevant KPIs highlighted some criticalities and improvement pathways. Some of these have already been implemented in the analyzed company in terms of environmental sustainability, such as actions to improve energy management and reduce the use of hazardous materials. Also, from a social point of view, some actions have been developed, such as the elaboration and publication of an ethic code of conduct shared with all the suppliers. More detailed and quantitative results are not currently provided for confidentiality since the company wants to implement its own communication and dissemination campaign.

The same approach is now being repeated in the district for at least one actor of the supply chain or for more companies according to their expression of interest. In fact, the greatest impact on each pillar of sustainability will be ensured by implementing circular actions at the district/supply chain level.

Industrial sector	Brief description	Application approach
• Use of plastics in agriculture	The ViVACE® tool is used to assess potential solutions to make the use of plastics in agriculture more sustainable, for example: • improving the recycling of plastics anti-hail/insect nets; • replacing plastics with bio-based materials for mulching applications.	Tool applied to the products (see other plastics applications)
• Customized plastics/paper carrier bags • Lighting system manufacturing • Machines for plastics manufacturing	The ViVACE® tool is used to collect quantitative information to assess sustainability in three Italian companies in the selected sectors, with the aim to understand their current level of circularity and identify improvement pathways.	Tool applied to the process (see application in textile sector)

Table 2.
Application fields in which the ViVACE® tool is under development.

2.4 Other applications under development

The setting of the ViVACE® tool is under development in the other four applications at a starting phase. **Table 2** summarizes the main characteristics of these application fields.

3. Discussion and implications of the approach

According to the needs evaluated during the development of the new visualization tool, the versatility and capacity to be adapted to every product and industrial sector were fundamental and covered by only a few available tools in the literature. These features for the ViVACE® tool have been deeply demonstrated with the previous applications.

Providing a recognized classification of the analyzed applications is not easy in relation to the already mentioned fragmentation in defining CE and measurement methodologies [25, 53]. However, the authors propose a classification based on literature (both academic and grey literature and standards) that is already active about the proposition of a CE taxonomy with the aim to support the diffusion of circular actions, contributing to providing categories able to facilitate the development and access to finance, credit risk assessment, and transferability and replicability of projects, initiatives and investment across regions. In particular, four documents have been analyzed, integrated, and, when necessary, adapted to select useful proposed categories for the arrangement of the described ViVACE® applications in a framework able to specify its potential and adaptability. The analyzed documents are: one academic paper [54]; a report by the European Commission [53]; and two standards (BS 8001:2017, published; draft of the framework of the Italian project UNI1608856). **Table 3** explains the six categories selected from each reference to be used for ViVACE®.

According to this categorization, the ViVACE® tool applications can be characterized as in **Table 4**.

The main feature that characterizes the ViVACE® tool, which is well explained in **Figure 2**, is the integration of a bottom-up approach, considering what the practical actors of CE (mainly the industrial sector) need to define strategies to

Categories	Brief description	Options	Reference
Purpose	It describes the possible use of the ViVACE® tool and its results (adapted from "Usages").	• Improvement • Support for decision-making • Comparison (linear/circular) • Benchmarking • Communication • Certification • Etc.	[54]
Loops	It describes the typology of circular actions that is implemented.	Due to the fragmentation in this context, only the 14 categories defined in [53] are used, to limit the options.	[53, 54] UNI1608856
Supply chain stage	It describes the actors of the supply chains involved in the application.	• Design • Suppliers • Manufacturing • Distribution and sales • Use • End-of-life • Transversal	UNI1608856
Finding formats	It describes the outputs obtained/derivable by the ViVACE® tool (it is not strictly connected to "Format" used in [54]).	• Sector-specific KPIs • Managerial dashboard • LCA • Net Present Value • Etc.	[54]
Level	It describes the scale of the application.	• Micro (single company, products, consumers) • Meso (supply chains, symbioses, districts) • Macro (city, province, region or country)	[54] UNI1608856
Principle	It describes the basic principles on which the applications are designed.	• System thinking • Innovation • Stewardship • Collaboration • Value optimization • Transparency	BS 8001:2017

Table 3.
Categories adapted from the literature to describe the ViVACE® tool applications.

shift to the circular paradigm. In particular, this need is the availability of intuitive and quantitative information. The main novelty and strength of the ViVACE® tool are its capacity to starting from a lower level than the availability of information, which consists of the availability of all necessary data to obtain information. In practice, the ViVACE® tool simply "forces" the users to collect data in a structured and systematized form. The framework of the necessary data has been structured starting from knowing how the companies work (with materials and processes characterized by efficiencies and the use of energy, water, logistics, etc.), and since,

ViVACE® tool applications	Purpose	Loops (code used in [53])	Supply chain stage	Finding formats	Level	Principle
Phosphorus management	Support decision-making	Deployment of technologies for CE (1.c)	Manufacturing	Sector-specific KPIs/NPV	Micro	Stewardship
#CORRIPULITO	Comparison	Separate collection and reverse logistics of waste (3.a)	Transversal	Sector-specific KPIs	Meso	Collaboration
RICIRCOLA – Plastic Waste Free	Comparison	Design and production of circular products (1.a)	Transversal	Sector-specific KPIs	Meso	System thinking
Textile/footwear sector	Improvement/ Communication	Deployment of tools enabling CE strategies (4.a)	Manufacturing	Dashboard/LCA	Micro → Meso	Stewardship/ Transparency
Plastics use in agriculture	Improvement	Substitution or reduction of substances to enable CE (1.d)	Use/End-of-life	Sector-specific KPIs/LCA	Meso	Innovation
Carrier bags manufacturing	Improvement/ Communication	Deployment of tools enabling CE strategies (4.a)	Manufacturing	Dashboard	Micro	Stewardship
Lighting system manufacturing	Improvement/ Certification	Deployment of tools enabling CE strategies (4.a)	Manufacturing	Dashboard	Micro	Stewardship
Machines for plastics manufacturing	Improvement/ Communication	Deployment of tools enabling CE strategies (4.a)	Manufacturing	Dashboard	Micro	Stewardship

Table 4.
Categorization of the ViVACE® tool applications.

independently from products, processes, and sectors, but also from size, the organizational structure and functions of industries are very similar, the tool can be easily adapted to different contexts. Therefore, this approach results more promising and effective than imposing a set of KPIs to measure circularity (top-down approach), since the lack, inconsistency, low quality, and unreliability of certain data could generate a partial, inconsistent and misleading evaluation of indications, difficult to understand and compare [23, 55].

The further step of this proposed approach, which starts from the bottom level, is to tackle another identified issue, which is the complexity to shift from one scale to another [22]. The micro-scale KPIs are typically based on physical parameters and linked to technological aspects, while high-level indicators, such as socio-institutional indexes, climate change, and the targets defined by the SDGs, require a combination and integration of a set of KPIs used for the monitoring of CE [55]. Clearly identifying the set of KPIs and the way with which combining them is a challenge, but assessing the macro level is fundamental for the establishment and monitoring of policy coherence and achievement of the targets at regional, national, and international scale. Probably, the use of multi-criteria decision-making methods, as tools able to solve complex problems by simultaneously taking into consideration multiple and different criteria, could be the solutions, as already proposed for the definition of circular business strategies in [56] (micro-level application). In particular, the authors are currently working on how to aggregate KPIs used in the described applications of the ViVACE® tool to evaluate their contribution to important international strategies, such as the new EU Circular Economy Action Plan, the Green Deal, and the SGDs.

The main implications of this work are four-fold. (i) Firstly, it describes a comprehensive research method able to overcome the gap identified in shifting from CE theory to practice, which is the lack of clear and consistent approaches to actually assess the circularity and sustainability of products, processes, business models, and strategies. The flexibility and versatility of the proposed tool, as demonstrated by different applications, concerns the systematization of data collection to make data available for the evaluation of useful information and KPIs. Consequently, as demonstrated by this study, the ViVACE® tool is a promising and effective means to activate the evaluation, and widespread use of relevant KPIs collected in literature [19, 22–24]. The applications of the ViVACE® tool also provide a series of quantitative information about the involved sectors and/or initiatives, most of them not still available. Consequently, they can guide researchers in the design and development of improving solutions (products, processes, technologies, etc.). (ii) The second implication of this research involves the industrial managers and other practitioners, such as consultants. According to the purposes showed in **Table 2**, the companies can use the ViVACE® tool to evaluate and monitor useful, intuitive, and quantitative information to improve their processes, products, and businesses, in terms of sustainability, to compare them with competitors and to externally communicate (e.g., to costumers and/or to obtain certifications) their current results, and strategies to advance their situation achieving some targets. (iii) The third implication, applicable at micro level as the previous ones, is linked to providing support for public and private financial bodies. Since the ViVACE® tool is able to measure the potential of different CE actions and scenarios applied to several industrial sectors, it can be used to compare different opportunities to be funded, guiding the decision towards the most sustainable and less risky solutions. (iv) Finally, the ViVACE® tool has the capacity to arrange micro-level information, which, if suitably aggregated, can be used to evaluate the contribution of micro-level CE activities on regional, national and international policies. At macro-level, institutions and policy-makers could use the tool to simulate the scenarios potentially prepared by some policies and incentives, to support the consistent and robust design of these tools to boost the transition to an effective CE.

4. Conclusions

The transition to a circular economy, as a more sustainable and resilient production and consumption model, is increasingly urgent: it will not consist only of an opportunity, but it will be fundamental at different scales for companies, institutions, and governments. The actors able to make this transition effective could collect the benefits of greater competitiveness since before. Since the delineation of this transition is not easy, also due to the nature of the circular economy, typically cross-sectorial and activated by a network of different actors, it becomes very important to have available information to quantify benefits and risks, compare different options, and hence support the decision-making process. The proposed tool ViVACE® has been demonstrated to be able to provide this quantitative information through its adaptation capacity to different industrial sectors and CE actions. Its applications in different contexts, and the types and formats of results that it is able to provide, opens new potential functions and also highlights limits in certain uses and specific needs to be solved and integrated with enhanced versions of the tool. Consequently, deep use of the tool will allow it to become more robust and consolidated, even if some of its features already result in innovation and are still not covered by any other available tool.

Author details

Augusto Bianchini* and Jessica Rossi
Department of Industrial Engineering, University of Bologna, Forlì, Italy

*Address all correspondence to: augusto.bianchini@unibo.it

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