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Aims and Scope

The European Journal of Social Impact and Circular Economy (EJSICE) is an online open-access journal published by the University of Turin. The Journal publishes quarterly (every four months) articles that contribute to the development of both theory and practice of research methods used throughout the field of social impact and circular economy. The readers of this Journal are mainly researchers, academics, PhD students and other practitioners.

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The Emerging Circular Economy Trends of United Arab Emirates (UAE) Universities

Shankar Subramanian Iyer[1]

[1] S.P. Jain Institute of Global Management, Block 5 Academic City - Dubai, United Arab Emirates
shankar.subramanien@gmail.com

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Abstract

This paper examines the emerging circular economy trends in universities in the United Arab Emirates (UAE). The circular economy is a model that aims to reduce waste and maximize the use of resources, promoting sustainable development. The study analyses UAE universities' various initiatives to adopt circular economy practices, including using renewable energy, sustainable building design, and waste reduction strategies. The paper also discusses the challenges and opportunities for implementing circular economy practices in universities in the UAE and highlights examples of circular economy initiatives in various universities. The paper concludes by providing recommendations for universities in the UAE to promote sustainable practices further and contribute to the circular economy movement. The findings of this study provide insights into the emerging circular economy trends in universities in the UAE and offer directions for future research in this area. The ADKAR change management can be adapted to inspire the CE initiatives of the UAE Education sector.

Keywords: Circular economy; eco-design: business education; management education, ADKAR

1. Introduction

The concept of circular economy has been gaining momentum in recent years to promote sustainable development and reduce waste. The United Arab Emirates (UAE) has also recognized the importance of adopting circular economy practices to address environmental challenges and promote sustainable growth. Universities in the UAE are playing a vital role in this transition by implementing circular economy practices and promoting sustainability education. This paper focuses on exploring the emerging trends of the circular economy in universities in the United Arab Emirates (UAE) (Dave et al., 2022). The circular economy is a model that aims to minimize waste and optimize resource usage, thus promoting sustainable development. The study delves into the various initiatives that UAE universities have taken to implement circular economy practices. These initiatives include using renewable energy sources, sustainable building design, and waste reduction strategies (Campra et al., 2021).

This paper explores the emerging trends of the circular economy in universities in the UAE. It aims to provide insights into the initiatives taken by these universities to adopt circular economy practices, the challenges and opportunities they face, and the impact of these practices on sustainable development. The key challenges include the need for more awareness and understanding of circular economy principles, the need for significant investments, and the need for clear regulatory frameworks. However, the study also highlights the benefits of adopting circular economy practices, such as reducing costs, improving the environmental footprint of universities, and promoting innovation and collaboration. The paper also provides examples of circular economy initiatives implemented in various universities in the UAE. These examples range from small-

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scale projects such as composting and recycling to large-scale initiatives such as using renewable energy in campus buildings (Dantas et al., 2021).

The UAE is a rapidly developing country with a growing population, which puts pressure on natural resources and generates significant waste. In response to these challenges, the UAE has launched several initiatives to promote sustainability and reduce waste. One of the most prominent initiatives is the UAE Vision 2021, which aims to promote sustainable development and reduce the country's ecological footprint.

Universities in the UAE have also recognized the importance of adopting circular economy practices to promote sustainability and reduce waste. These universities have implemented various initiatives, such as using renewable energy sources, sustainable building design, and waste reduction strategies. Moreover, universities in the UAE are also promoting sustainability education to raise awareness and encourage students to adopt sustainable practices in their daily lives(Lusk et al., 2020). Despite these efforts, universities in the UAE need help in implementing circular economy practices. These challenges include the lack of awareness about circular economy principles, the need for significant investments, and the absence of clear regulatory frameworks.

Therefore, this paper aims to provide an overview of the emerging circular economy trends in universities in the UAE, analyze the challenges and opportunities for implementing circular economy practices, and offer recommendations for universities to promote sustainable practices further and contribute to the circular economy movement. The paper concludes by offering recommendations to the UAE universities to promote sustainable practices and contribute to the circular economy movement. These recommendations include increasing awareness and education about circular economy principles, developing clear regulatory frameworks, encouraging collaboration among universities, and investing in research and development of circular economy solutions. Overall, this paper provides valuable insights into the emerging circular economy trends in universities in the UAE, highlighting the challenges and opportunities for implementing circular economy practices. The findings of this study offer directions for future research in this area and provide a roadmap for universities in the UAE to promote sustainable practices and contribute to the circular economy movement (Kirchherr et al., 2019).

The UAE education sector is transforming Smart Universities and Smart Education systems. This transformation is spearheaded by the Smart Government initiatives of various Emirates, such as Dubai and Abu Dhabi. The aim is to make the education sector more sustainable, efficient, and effective by reducing paper usage, streamlining administration, and using emerging technologies. One of the most significant changes is the move towards paperless offices and administration. This means universities use digital platforms to record and issue certificates, reducing paperwork and making the process more efficient. This move towards paperless administration is a step towards sustainability, as it reduces paper usage and waste (Mendoza et al., 2019).

The Smart Government initiatives are also promoting emerging technologies such as Blockchain, Cloud-computing, Virtual Reality, AI, and Machine learning in education to further sustainability and standardize education curricula in the UAE. For example, Blockchain technology can securely store education records, making them easily accessible and tamper-proof. Cloud computing can store and access educational resources and data, making it easier for students and teachers to collaborate and share information. Virtual Reality can create immersive learning experiences, making education more engaging and interactive. AI and Machine learning can be used to personalize learning, adapting to the needs and preferences of individual students. These Smart Education initiatives are making the education sector more sustainable and creating opportunities for implementing circular economy initiatives. For example, Blockchain technology can be extended to implement circular economy practices by creating a secure and transparent system for tracking and managing waste. This can help reduce waste and increase the efficiency of recycling and waste management processes (Ghareeb et al., 2020).

Overall, the UAE Education sector's move towards Smart Universities and Smart Education systems is a positive step towards creating a more sustainable and efficient education sector. Emerging technologies and Smart Government initiatives are creating opportunities to implement circular economy practices and promote sustainability in the education sector. (Iyer, 2022).

Given the previous gap analysis, our paper aims to explore the following research questions:

a) What are the current circular economy trends being adopted by UAE universities?

b) What challenges and opportunities do UAE universities face in implementing circular economy practices?

c) How effective are the circular economy initiatives being implemented by UAE universities in promoting sustainability and reducing environmental impact?

d) What are the best practices for implementing circular economy initiatives in UAE universities?

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2. Literature review

The concept of the circular economy is gaining increasing importance in the global economy, focusing on sustainability and resource efficiency. UAE universities also recognise the need to adopt circular economy practices to promote sustainability and reduce environmental impact. This literature review explores UAE universities' emerging circular economy trends and the challenges and opportunities associated with their implementation.

2.1 Circular economy trends in UAE universities

UAE universities are increasingly adopting circular economy practices to promote sustainability and reduce environmental impact. These practices include waste reduction, recycling, and using renewable energy sources. For example, the Masdar Institute of Science and Technology, based in Abu Dhabi, has implemented a zero-waste policy, where waste is reduced and recycled to minimize its environmental impact. Similarly, the American University of Sharjah has implemented a sustainability plan, which includes using renewable energy sources such as solar power and reducing water consumption.

2.2 Challenges and opportunities

The implementation of circular economy practices in UAE universities has its challenges. One major challenge is the need for more awareness and understanding of the circular economy concept among stakeholders, including students, faculty, and administrators. This can hinder the adoption and implementation of circular economy practices. The lack of infrastructure and resources for waste management and recycling can also pose a challenge.

However, several opportunities exist for implementing circular economy practices in UAE universities. The UAE government has committed to promoting sustainability and reducing its environmental impact through initiatives such as the UAE Vision 2021, which aims to achieve a sustainable environment and infrastructure. This allows universities to align their sustainability efforts with the government's objectives and collaborate on circular economy initiatives. UAE universities' emerging circular economy trends demonstrate a commitment to sustainability and resource efficiency. However, the challenges associated with implementing circular economy practices must be addressed to ensure their effectiveness. The opportunities for collaboration with the UAE government on sustainability initiatives provide an avenue for universities to make a significant impact on the circular economy and promote a sustainable future in the UAE

2.3 Gaps in the literature

Despite the growing interest in circular economy practices in UAE universities, gaps in the literature need to be addressed. Most of the available literature is descriptive and based on case studies, which limits our understanding of the impact of these practices on sustainability and resource efficiency. While some studies have identified the challenges associated with implementing circular economy practices in UAE universities, there is a need for more in-depth research on these challenges, including the barriers to adoption and the strategies for overcoming them. The engagement of stakeholders, including students, faculty, and administrators, is critical for the successful implementation of circular economy practices in universities. However, there needs to be more focus on stakeholder engagement in the available literature.

2.4 Circular economy – present and future scenario

The circular economy is a newer concept and not so known till now to most people. Most people are still caught in the linear sustainability economy. The circular economy (CE) model considers a reduction in the negative impact on the environment, thus moving away from the traditional linear business model, where the final product is value creation after reaching its highest consumption point. In the CE, the main goal is to enhance the product's life span, create goods with a long-life cycle and focus on services rather than products (Figure 1). The focus should be on the change management to shift from a linear to a circular economy. The ADKARI model (Figure 2) is a perfect application for this chance management, as

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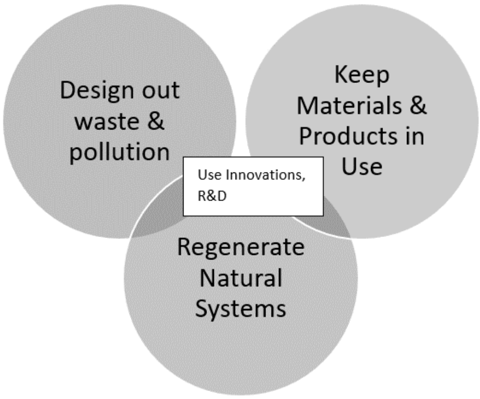
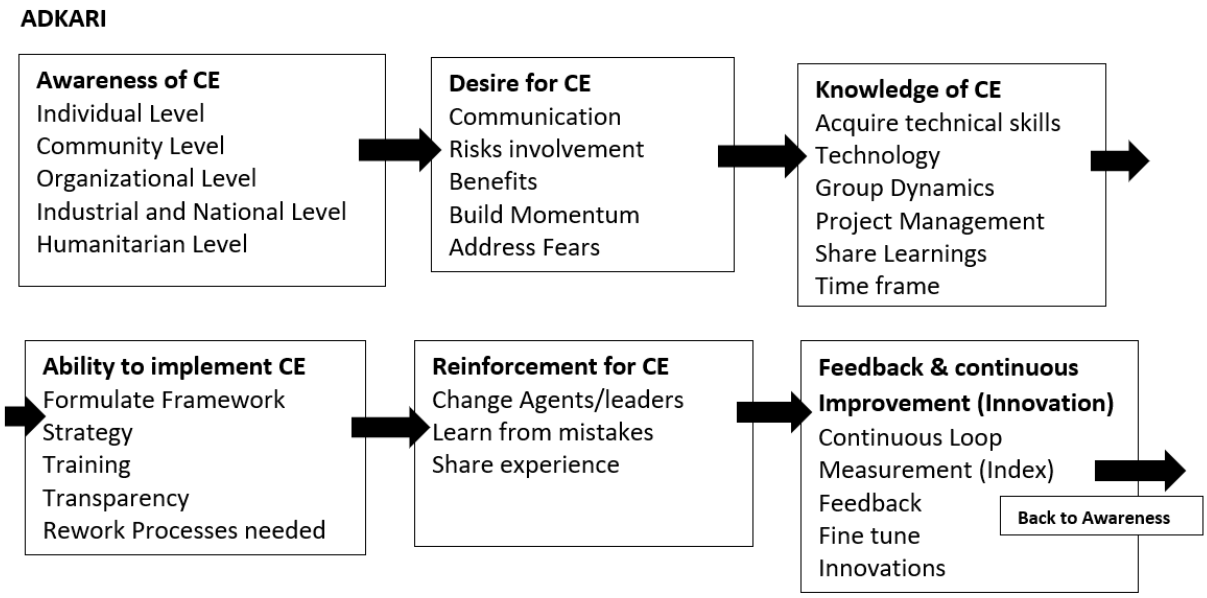
discussed below. The Circular economy has primarily three pillars shown in the figure, and the fourth can use innovations through R&D to achieve the other three (Baars et al., 2021; Iyer et al., 2020).

Figure 1. Innovations and R&D



Source: Authors' elaboration

Figure 2. The ADKARI Model



Source: Authors' elaboration

3. The ADKARI model

3.1 Awareness of circular economy

The circular economy is a concept that aims to promote sustainability by reducing waste and maximizing the use of resources. Awareness of circular economy can be looked at from different levels, including individual, community, organizational, industrial or national level, and humanitarian levels. At the individual level, awareness of the circular economy involves understanding the importance of reducing waste and adopting sustainable practices in daily life, such as recycling, composting, and reducing energy consumption. It also involves promoting the idea of a circular economy to others, such as family and friends, to increase awareness and encourage the adoption of sustainable practices. At the community level, awareness of circular economy involves promoting sustainable practices and adopting circular economy principles in

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local communities. This includes encouraging local businesses to adopt sustainable practices, supporting local recycling programs, and promoting the use of locally sourced products to reduce waste and promote sustainability. At the organizational level, awareness of circular economy involves promoting sustainable practices and using circular economy principles in organizations and businesses. This includes implementing sustainable supply chain practices, reducing waste in production processes, and promoting using renewable energy sources. At the industrial or national level, awareness of circular economy involves promoting the adoption of circular economy principles in industries and at the national level. This includes promoting sustainable manufacturing practices, reducing waste in production processes, and using renewable energy sources to reduce carbon emissions. At the humanitarian level, awareness of circular economy involves promoting sustainable practices in developing countries and using circular economy principles in humanitarian efforts. This includes promoting sustainable agriculture practices, reducing waste in refugee camps, and using renewable energy sources in humanitarian aid efforts. In summary, awareness of circular economy can be promoted at different levels, including individual, community, organizational, industrial or national, and humanitarian levels. This involves promoting sustainable practices, reducing waste, and using renewable energy sources to promote sustainability and reduce environmental degradation (Mukwenda et al., 2019).

3.2 Desire for circular economy

The desire for a circular economy can be driven by various factors, such as communication, risks involvement, benefits, building momentum, and addressing fears. Effective communication is essential in creating a desire for a circular economy. Communication efforts should emphasize the importance of sustainability and the benefits of a circular economy in reducing waste and promoting the efficient use of resources. Communication can be achieved through different channels, such as social media, advertising, public relations, and education programs. Involving stakeholders, such as businesses, governments, and communities, in the circular economy process can help create a desire for the circular economy. By involving stakeholders in the process, they will understand the risks of not adopting sustainable practices and the benefits of a circular economy. Communicating the benefits of a circular economy can create a desire for it. The benefits include reducing waste, conserving natural resources, creating jobs, and reducing greenhouse gas emissions. These benefits positively impact the environment, economy, and society (Kirchherr et al., 2019). Building momentum is important in creating a desire for a circular economy. This can be achieved by creating partnerships, collaborations, and alliances. The momentum created can drive change and inspire others to adopt sustainable practices. Addressing fears related to a circular economy can create a desire for it. Some fears include the loss of jobs, the cost of implementing sustainable practices, and difficulty changing consumer behaviour. Addressing these fears can help stakeholders understand that a circular economy can create new jobs, save costs in the long run, and that change is possible. By doing so, stakeholders will understand the importance of adopting sustainable practices and be motivated to promote a circular economy (Rodriguez, 2020).

3.3 Knowledge of circular economy

Knowledge is the major contributor to CE successful implementation, and for this, the participants need to acquire technical skills, technology know-how, Team dynamics skills, project management skills, collaborate with others to share learnings and within the decided time frame. Knowledge of circular economy requires acquiring technical skills and technology competency. Technical skills refer to using tools, machinery, and other equipment to perform specific tasks. In the context of a circular economy, technical skills are required to design products that can be easily recycled, repaired, or reused. Technical skills are also needed in waste management, recycling, and upcycling processes (Kirchherr et al., 2019). Technology competency refers to the knowledge and ability to use technology to achieve specific goals. In the context of a circular economy, technology competency is essential in developing and implementing innovative technologies that support circular economy principles. This includes using digital platforms to facilitate the exchange of resources and materials, developing smart waste management systems, and using renewable energy sources. Technical skills and technology competency can be acquired through various means, such as training programs, workshops, and educational courses. These programs can help individuals and organizations understand the principles of circular economy, learn about sustainable practices, and gain technical skills and technology competency. In addition, collaboration with other stakeholders can also help in acquiring technical skills and technology competency. Partnerships with technology companies, research institutions, and other organizations can provide access to the latest technologies and knowledge supporting circular economy practices. By doing so, stakeholders can design products that support circular economy principles, implement sustainable practices, and

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create innovative solutions that promote a circular economy. Group dynamics refer to how people interact and work together in a group setting. In a circular economy, group dynamics promote stakeholder collaboration, communication, and teamwork. This includes engaging stakeholders from different sectors and disciplines to work together towards common goals, sharing ideas and perspectives, and building trust and relationships. Project management is also crucial in implementing circular economy practices. This involves setting clear goals, timelines, and budgets and identifying and managing risks and stakeholders. Effective project management ensures that circular economy initiatives are implemented efficiently and effectively. Shared learnings are also important in promoting knowledge of the circular economy. This involves sharing best practices, successes, and challenges among stakeholders. By learning from each other, stakeholders can identify opportunities for improvement and develop more effective circular economy strategies. Finally, a clear time frame is essential in implementing circular economy practices. This involves setting realistic timelines and milestones, monitoring progress and adjusting strategies. A clear time frame ensures that circular economy initiatives are implemented promptly and effectively (Stacy et al., 2021).

3.4 Ability to implement circular economy

Circular Economy is an economic system that aims to eliminate waste and promote the continual use and regeneration of resources. To implement Circular Economy, a formulated framework is needed to establish the principles and guidelines for the process. A strategy is also necessary to identify the areas where Circular Economy can be implemented, such as product design, resource management, and waste reduction. This strategy should be flexible to adapt to changing circumstances and evolving technologies. Training is crucial to ensure that all stakeholders, including employees, suppliers, and customers, understand the principles and practices of the Circular Economy. Transparency is also essential to build trust and accountability among all parties involved. Finally, rework processes are necessary to ensure that any waste generated during the production or consumption cycle is reused or recycled. This can include repurposing materials, repairing products, or recycling waste back into the production process. By adopting this approach, we can promote sustainable and responsible resource use and create a more resilient and equitable economy (Kachian et al., 2018).

3.5 Reinforcement for circular economy

Change agents or leaders are individuals or groups who advocate for and initiate change within an organization or community. They can help promote Circular Economy's principles and encourage others to adopt sustainable practices. By providing leadership and guidance, change agents can help to reinforce the importance of the Circular Economy and ensure that it is integrated into the organization's culture and operations. Learning from mistakes is also an important aspect of reinforcement. When mistakes are made, it provides an opportunity to learn and improve. By analyzing the causes of mistakes and identifying ways to prevent them in the future, organizations can strengthen their commitment to Circular Economy and reinforce the importance of sustainable practices. Sharing experiences is another way to reinforce Circular Economy. Organizations can inspire others to adopt sustainable practices by sharing success stories and best practices. This can be done through case studies, workshops, and other forms of communication. Sharing experiences can also help to build a sense of community and collaboration around the principles of Circular Economy. In summary, reinforcement is critical for successfully implementing the Circular Economy. By leveraging change agents/leaders, learning from mistakes, and sharing experiences, organizations can strengthen their commitment to sustainability and promote the continual use and regeneration of resources. (Khan et al., 2019).

3.6 Feedback and continuous improvement through innovations

The last step that has been suggested and added by the researchers as Improvement in terms of Innovation is the continuous development using R&D. The feedback can be given based on the measurement using the CE index, which is introduced below whether the implementation is going as expected or fine-tuning is required to set it on track. The innovations will start the whole cycle again, spreading awareness to measure the effectiveness of implementation Feedback and continuous improvement are essential for successfully implementing a Continuous Loop in a Circular Economy (Kirchherr et al., 2019). This involves using measurement, feedback, fine-tuning, and innovation to create a more sustainable and efficient system. Measurement is a crucial part of the Continuous Loop process. It involves using an index, such as a sustainability index, to measure the organisation's activities' environmental, social, and economic impacts. By measuring

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these impacts, the organization can identify areas for improvement and track progress over time. Feedback is another essential component of the Continuous Loop process. It involves collecting feedback from stakeholders, such as customers, employees, and suppliers, on the organization's sustainability efforts. This feedback can be used to identify improvement areas and develop new strategies to enhance sustainability. Fine-tuning involves small adjustments to the organization's processes and practices to improve sustainability. This can involve optimizing supply chain efficiency, reducing waste, and reducing energy consumption. By fine-tuning these processes, the organization can reduce its environmental footprint and improve its overall sustainability. Innovation is also important for continuous improvement in a Circular Economy. This involves developing new technologies, products, and services that promote sustainability and reduce waste. Innovation can help to create new markets and opportunities for the organization, while also contributing to more sustainable outcomes. (Jia et al., 2020).

3.7 Circular economy index

A Circular Economy index is a tool that measures an organization's progress towards implementing circular economy principles. This index typically includes a set of indicators that assess the organization's performance in areas such as resource efficiency, waste reduction, and product design. A Circular Economy index could be developed for UAE universities to measure their progress towards implementing circular economy principles. Resource efficiency - measures the university's use of natural resources such as water, energy, and materials. This could include tracking energy consumption, water usage, and waste generation. Waste reduction - measures the university's efforts to reduce waste and increase recycling. This could include tracking the amount of waste generated, the percentage of recycled waste, and implementing waste reduction strategies such as composting and reusing materials. Product design - measures the university's efforts to design products and services that promote circularity. This could include tracking the use of sustainable materials, implementing product design strategies such as modular design, and developing new circular products and services. Stakeholder engagement - measures the university's efforts to engage stakeholders (such as students, faculty, and staff) in circular economy principles. This could include tracking the implementation of circular economy education programs, using circular economy messaging in marketing and communications, and developing circular economy partnerships with local businesses and organizations. This can help to promote sustainable practices and support the transition towards a more circular economy in the UAE (De Oliveira et al., 2021).

4. Alternative solutions to problems by leveraging the prospects

UAE Universities can contribute to the CE prospects by leading a lot of initiatives. Some of the above-illustrated initiatives are already work in progress, and some are suggestions from the industry to the sector to contribute more (Figure 3).

Figure 3. Education sector in UAE

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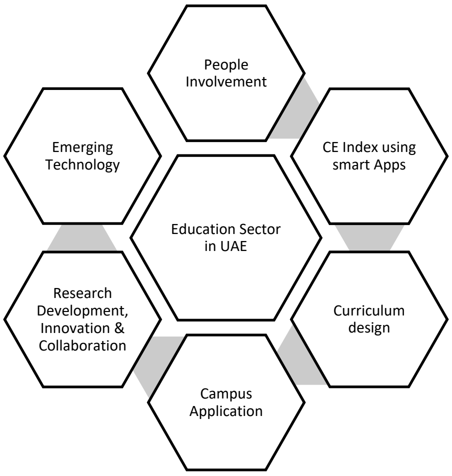

Source: Author's elaboration

4.1 Curriculum design for the circular economy

Curriculum design for the Circular Economy is the process of developing educational programs and courses that equip students with the knowledge, skills, and values needed to understand and apply circular economy principles in their future careers (Kleba et al., 2020).

i. Identify learning objectives: This step involves determining what knowledge and skills students should acquire through the curriculum. Learning objectives should be specific, measurable, achievable, relevant, and time-bound.
ii. Select relevant topics: This step involves selecting topics that are relevant to the Circular Economy, such as resource efficiency, waste reduction, product design, and sustainable business practices. Topics should be aligned with the learning objectives.
iii. Develop learning activities: This step involves creating learning activities that engage students and enable them to apply circular economy principles. Activities could include case studies, problem-based learning, and group projects.
iv. Choose relevant teaching methods: This step involves selecting teaching methods that are appropriate for the learning objectives and activities. Teaching methods could include lectures, discussions, and experiential learning.
v. Incorporate assessment strategies: This step involves developing assessment strategies that measure student learning and achievement of the learning objectives. Assessment strategies could include exams, essays, and presentations.
vi. Integrate technology: This step involves integrating technology into the curriculum to enhance student learning. The technology could be used for online learning, virtual simulations, and collaborative work.
vii. Review and revise: This step involves reviewing and revising the curriculum to ensure it is up-to-date, relevant, and aligned with the learning objectives.

Curriculum design for the Circular Economy should be interdisciplinary and incorporate a range of subjects, including engineering, business, environmental science, and social sciences. By integrating circular economy principles into the curriculum, students can develop the knowledge and skills to promote sustainable practices and support the transition towards a more circular economy (Nunes et al., 2018).

4.3 Research & development, collaborations & innovations

Research and development (R&D) and collaborations & innovations can be vital in ensuring a circular economy in UAE universities. UAE universities can invest in R&D to develop sustainable technologies that promote the circular economy. For example, the Masdar Institute of Science and Technology or Khalifa University in Abu Dhabi has developed renewable energy technologies such as solar panels and wind turbines. UAE universities can collaborate with industry partners to develop innovative solutions that promote the circular economy (Kirchherr et al., 2019). For example, the Dubai Electricity and Water Authority (DEWA) has partnered with the American University of Dubai to develop a solar-powered air

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conditioning system. UAE universities can implement circular business models that promote product reuse, repair, and recycling. For example, the Dubai Future Accelerators program has partnered with universities to develop circular business models for waste management. UAE universities can educate students and raise awareness about the importance of the circular economy. For example, the University of Dubai has implemented a sustainability-focused curriculum that teaches students about sustainable business practices and the circular economy. UAE universities can provide funding for circular economy projects that promote sustainable practices. For example, the Abu Dhabi Sustainability Week funds research and development projects promoting sustainability and circular economy. R&D and, collaborations & innovations can ensure a circular economy in UAE universities by developing sustainable technologies, collaborating with industry partners, implementing circular business models, educating students, and providing funding for circular economy projects. By promoting a circular economy, UAE universities can contribute to a sustainable future for the UAE and the world. (Brown et al., 2019).

4.4 Emerging technology usage

Emerging technology usage can play a significant role in supporting the Circular Economy in UAE Universities. IoT is a network of devices connected to the internet that can communicate with each other. In universities, IoT technology can monitor and optimize resource consumption, such as energy and water usage. This can help universities reduce waste and promote a circular economy (Kirchherr et al., 2019). 3D printing is a technology that allows objects to be created by adding layers of material. In universities, 3D printing can create objects from recycled materials, reducing waste and promoting a circular economy. Blockchain is a decentralized digital ledger that records transactions securely and transparently. In universities, blockchain technology can track the provenance of materials, ensuring that they are sustainably sourced and promoting a circular economy. AI is the use of computer systems to perform tasks that would normally require human intelligence. In universities, AI can be used to optimize resource consumption, predict maintenance needs, and identify opportunities for waste reduction, promoting a circular economy. AR is a technology that overlays digital information into the real world. In universities, AR can be used to create immersive educational experiences that teach students about sustainable practices and the circular economy. Emerging technology usage can support UAE universities' Circular Economy by optimising resources, reducing waste, promoting sustainable sourcing, and creating immersive educational experiences. By leveraging the power of technology, UAE Universities can contribute to a sustainable future for the UAE and the world. (Jose et al., 2020).

4.5 People involvement

People's involvement is crucial for enhancing Circular Economy in UAE Universities. People's involvement is necessary to encourage participation in circular economy initiatives. Students, faculty, and staff need to be engaged in the planning and implementing of circular economy initiatives, and their feedback needs to be considered. People's involvement is necessary to implement behavioural changes that support circular economy initiatives. Students, faculty, and staff must be educated on sustainable practices and provided with the necessary tools and resources to implement them. People's involvement is necessary to encourage innovation in circular economy initiatives (Kirchherr et al., 2019). Students, faculty, and staff can contribute to developing new technologies, processes, and practices that support circular economy principles. People involvement is necessary to promote collaboration between different departments and stakeholders in the university. Circular economy initiatives require the collaboration of various departments, including facilities management, procurement, and sustainability. People's involvement is necessary to enhance the Circular Economy in UAE Universities. By promoting awareness, encouraging participation, implementing behavioural changes, encouraging innovation, and promoting collaboration, UAE Universities can contribute to a sustainable future for the UAE and the world. The implementation and success of the CE project depend on the People involved and their wholehearted participation. First, the people need to convince of the need for the CE requirements, importance and benefits, which proper training and workshops on the topics can augment. The People's involvement can be consolidated by introducing extrinsic and intrinsic rewards to motivate them (Bonato et al., 2018).

4.5 Circular economy using smart app

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The CE Index is a tool that measures the extent to which Circular Economy principles are being implemented in an organization. A smart application can collect data on circular economy practices in UAE universities. This can help identify areas where improvements can be made and track progress over time. Using a smart application to track CE Index, UAE universities can increase awareness of circular economy principles among students, faculty, and staff. This can encourage greater participation and a culture of sustainability (Kirchherr et al., 2019). A smart application can help identify areas where innovation can be applied to improve circular economy practices. This can lead to new technologies, processes, and practices supporting circular economy principles. Using a smart application to track CE Index can give UAE universities a clear picture of their progress towards circular economy goals. This can help identify areas where improvements can be made and track progress over time. A smart application can facilitate collaboration between different departments and stakeholders in UAE universities. UAE universities can work together to improve their circular economy practices by providing a platform for sharing data and ideas. CE Index using a smart application, can boost Circular Economy in UAE Universities by improving data collection, increasing awareness, encouraging innovation, monitoring progress, and facilitating collaboration. Using such a tool, UAE universities can contribute to a sustainable future for the UAE and the world. The CE Index development can be a major contribution to the area of existing knowledge and help in measuring the Organization's current initiatives on a standardized scale compared to the other Industrial initiative and can make suggestions to implement more projects. The Index will induce competitiveness among the various organizations and help the cause of CSR and CE (Figure 4) (Upadhyay et al., 2021).

Figure 4. Sustainable Development Goals (SDGs)

Source: Author's elaboration

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Table 1. Sustainability Development Goals[1] (SDGs)

SDG No.	Description of how the UAE Education sector can develop this SDG
1.	Eradicate Poverty by Education, which UAE Education sector can contribute
2.	Make Learners employable and as Entrepreneurs
3.	Train People on Well-Being and Health and spread awareness and run Research Projects.
4.	Standardized Common Circular Economy Curriculum
5.	Gender Equality exemplary practices at the UAE Education sector organizations
6.	Awareness and Experimental learning at the Campus
7.	Implement Projects on campus & Collaborate with Industry, Design Curriculum for these projects
8.	UAE education can develop Research, encourage innovativeness in renewable energy, tie-up with Industry to partner more projects
9.	UAE Education is recognized as economic contributor as education Hub for the Middle East and the many collaborations with the industry, is leading the way forward
10.	UAE Education lead Research & Development initiatives and implement Innovations that will contribute to CE and to build Infrastructure for such future initiatives.
11.	UAE Education can spread awareness and initiatives for building Smart cities and communities like Dubai and Abu Dhabi.
12.	The Collaboration with the Industry the UAE Education sector can lead initiatives towards responsible consumption and production of goods, products, services to CE and away from the linear economy.
13.	The UAE Education can build Ecological, Economical Curriculum to spread awareness of the Human action on Nature and the subsequent climate changes.
14.	The UAE Education can spread awareness of the impact of Human activities affecting Ocean lives and actions to avoid such impact.
15.	The UAE Education can spread awareness of the impact of Human activities affecting lives on Land and actions to avoid such impact.
16.	Institutes like UNEP, WHO should educate the people in collaboration with Government like UAE, involving the Education sector to spread Peace & Justice.
17.	The UAE Education collaborates with the Public and Private Companies to achieve CE goals leading to sustainability in Business.

Source: Author's elaboration

The SDGs of the UN shown in Table 1 can be extended to be the Circular Economy initiatives for the UAE Education sector. The above table shows the contribution of the UAE education sector towards the SDGs, making them CE goals that can be reworked as Circular Economy Development Goals (CEDGs) in the future (Rodriguez-Anton et al., 2019). The Circular Economy of UAE Universities can contribute to several Sustainable Development Goals (SDGs) set by the United

[1] https://sdgs.un.org/

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Nations. The Circular Economy of UAE Universities can promote responsible consumption and production by reducing waste and promoting the reuse and recycling of materials (SDG 12). The Circular Economy of UAE Universities can contribute to climate action by reducing greenhouse gas emissions through renewable energy, energy-efficient technologies, and sustainable practices (SDG 13- Climate Action). The Circular Economy of UAE Universities can provide quality education by integrating Circular Economy principles and practices into the curriculum, providing students with the knowledge and skills needed to build a sustainable future (SDG 4- Quality Education). The Circular Economy of UAE Universities can promote innovation and infrastructure development by encouraging the adoption of new technologies and processes that support Circular Economy principles (SDG 9- Industry, Innovation, and Infrastructure). The Circular Economy of UAE Universities can contribute to sustainable cities and communities by promoting renewable energy, reducing waste, and encouraging sustainable practices (SDG 11- Sustainable Cities and Communities). The Circular Economy of UAE Universities can foster partnerships by collaborating with local communities, businesses, and government agencies to promote sustainable practices and achieve the SDGs (SDG 17- Partnerships for the Goals). In summary, the Circular Economy of UAE Universities can contribute to several SDGs, including responsible consumption and production, climate action, quality education, industry, innovation, infrastructure, sustainable cities and communities, and partnerships for the goals (Kirchherr et al., 2019).

5. Barriers that need to be overcome for successful CE projects implementation

While implementing Circular Economy projects in UAE Universities can bring numerous benefits, several barriers must be addressed to ensure their success. One of the primary barriers to implementing Circular Economy projects in UAE Universities is a need for more awareness among stakeholders about the benefits of Circular Economy. Without a clear understanding of the principles and advantages of the Circular Economy, stakeholders may not see the value in investing in such projects (Kirchherr et al., 2019). The limited budget is another significant barrier to implementing Circular Economy projects in UAE Universities. Circular Economy projects often require significant investment in new technologies and processes, which may not be feasible for universities with limited financial resources. Resistance to change is another barrier to implementing Circular Economy projects. Some stakeholders may be resistant to change and unwilling to adopt new practices or technologies that support Circular Economy principles. Implementing Circular Economy projects requires specialized expertise and knowledge. UAE Universities may need to gain in-house expertise, making it challenging to implement Circular Economy projects successfully. Implementing Circular Economy projects in UAE Universities requires collaboration between stakeholders, including faculty, staff, and students. With collaboration, it can be easier to achieve the desired outcomes. To overcome these barriers, UAE Universities must invest in awareness-raising campaigns, allocate adequate budgets, provide training and capacity building to staff and students, and foster a culture of collaboration and innovation. By addressing these barriers, UAE Universities can successfully implement Circular Economy projects and contribute to a more sustainable future. The United Nations should recognize the CE development programs; the UN support will force governments to follow suit. The UAE government must announce policies that exempt and give concessions to Organizations developing CE initiatives. The individual mindset can be shifted by spreading awareness of employee benefits, importance, and individual rewards. The employees' participation in implementing these CE projects will accelerate and ensure their success. The major barriers are culture, lack of knowledge, lack of resources, and lack of priority for organizations to implement CE projects. The UAE Education sector should navigate these barriers successfully (Hart et al., 2019).

6. Discussion and conclusion

The objectives have been met and established. The SDGs of the UN can be extended to be the Circular Economy initiatives in the various sectors, as the study has shown for the UAE Education sector. The objective of suggesting CE initiatives to be implemented by the UAE Education sector has been met. The main contribution has been the management change perspective used to ensure the CE initiatives' successful implementation. The suggestions and recommendations will help Managers successfully implement CE initiatives with government policy support. The contribution of this study is the addition of innovation and a continuous feedback loop added to the ADKAR management change model. Quantitative and Qualitative studies can confirm these findings in future research and use other change management models to spearhead these

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CE initiatives in the Education sector and other sectors. "The Emerging Circular Economy Trends of UAE Universities" research makes several theoretical contributions to the field of circular economy.

a. Firstly, the research contributes to understanding the adoption of circular economy practices in the higher education sector. The study explores UAE universities' current circular economy practices, which provides valuable insights into the strategies universities can adopt to reduce their environmental impact and achieve sustainability goals. Secondly, the research contributes to the literature on the circular economy by identifying emerging trends in the circular economy practices of UAE universities. By analyzing the data collected from the survey, the research identifies several emerging trends universities can adopt to promote circular economy practices. These emerging trends include the use of renewable energy, the development of circular business models, and the adoption of sustainable procurement practices. Thirdly, the research contributes to developing a circular economy framework for the higher education sector. The study proposes a framework universities can use to guide their circular economy practices. The framework includes three key components: circular design and production, circular consumption and waste management, and circular business models and collaborations. Overall, "The Emerging Circular Economy Trends of UAE Universities" research provides a valuable contribution to understanding circular economy practices in the higher education sector, identifies emerging trends, and proposes a framework universities can use to guide their circular economy practices.

b. Firstly, the research provides practical implications for universities to adopt circular economy practices. The study identifies several emerging trends, such as the use of renewable energy, sustainable procurement practices, and circular business models. Universities can use this information to develop strategies to reduce their environmental impact, promote sustainability, and achieve sustainability goals. Secondly, the research has policy implications for policymakers promoting circular economy practices in higher education. The study proposes a framework that policymakers can use to guide universities in adopting circular economy practices. Policymakers can use this framework to develop policies and regulations encouraging universities to adopt circular economy practices. Thirdly, the research has practical and policy implications for the wider community. By adopting circular economy practices, universities can become leaders in promoting sustainable practices and reducing their environmental impact. This can inspire other businesses and institutions to adopt circular economy practices, leading to wider adoption of sustainable practices in the community. Overall, the research "The Emerging Circular Economy Trends of UAE Universities" has practical and policy implications for universities, policymakers, and the wider community in promoting circular economy practices and achieving sustainability goals.

8. Recommendations for future research

Further empirical research is needed to assess the effectiveness of circular economy practices in UAE universities. This research should focus on the impact of these practices on sustainability and resource efficiency. There is a need for more in-depth research on the challenges associated with implementing circular economy practices in UAE universities. This research should identify the barriers to adoption and the strategies for overcoming them. Future research should focus on stakeholder engagement, including the attitudes and perceptions of students, faculty, and administrators towards circular economy practices. This research should also explore the role of stakeholder engagement in the successful implementation of these practices. Comparative analysis of circular economy practices in UAE universities with universities in other countries can provide insights into the best practices and strategies for implementation. Future research should focus on the long-term impact of circular economy practices in UAE universities, including their impact on sustainability and resource efficiency. This can help universities assess their sustainability efforts' effectiveness and make adjustments as needed.

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Linking bioeconomy, circular economy, and sustainability: Trends, gaps and future orientation in the bio-based and biodegradable plastics industry

Eleonora Foschi[1], Selena Aureli[2], Angelo Paletta[3]

[1] University of Bologna, Department of Business Studies - Via Capo di Lucca 34, Bologna - Italy
eleonora.foschi3@unibo.it

[2] University of Bologna, Department of Business Studies - Via Capo di Lucca 34, Bologna - Italy
selena.aureli@unibo.it

[3] University of Bologna, Department of Business Studies - Via Capo di Lucca 34, Bologna - Italy
angelo.paletta@unibo.it

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Abstract

Bio-based and biodegradable plastics (BBPs) are innovative materials, wholly or partially produced from biomass, with the potential to enhance the circulation of resources in the biological cycle of the Ellen MacArthur Foundation's butterfly diagram. Although BBPs are generally considered more environmental-friendly than conventional plastics, robust scientific evidence is still missing. The lack of tools and metrics to assess the circularity and sustainability of the BBPs industry poses relevant challenges for its upscaling and contribution to climate neutrality goals in Europe. It also calls for adopting system and life cycle thinking, guided by multi-level and multi-dimensional examinations, which are used in this paper to build a comprehensive picture of trends, gaps and future orientations that may boost a sustainable circular bioeconomy in the sector. The value- chain based and multi-faceted SWOT analysis that emerged from the intersection of system and corporate data reveals the need to establish a combined circular bioeconomy strategy where incentives to integrated local supply chain, dedicated EPR schemes, eco-design guidelines, revised EoL standards, new clear labelling schemes and harmonised sustainability criteria should be prioritized and conjointly pursued to accelerate the transition towards a sustainable circular bioeconomy of the BBPs value chain.

Keywords: Bioeconomy; Circular economy; Sustainability; Bio-based and biodegradable plastics

1. Introduction

The exploitation of fossil resources has defined recent decades. The oil demand moved from 2,720 million tons in 1975 to 4,070 million tons in 2020 (Ibrahim et al. 2021). The gradual rise of a fossil-based society has contributed to a massive increase in global greenhouse gases (GHGs) (Center for International Environmental Law, 2018), accounting for 52.6 billion

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tons in 2020 (Jones et al., 2023). The chemical and plastics industries are responsible for around 7% of global GHG emissions (World Economic Forum, 2016). Because of the demand for fuel as a raw material input in addition to energy, the chemical sector (including the production of ethylene, propylene, benzene, toluene, mixed xylenes, ammonia and methanol) was responsible for 935 million tons of GHGs in 2022, while 1.6 billion tons of GHG emissions were emitted in the same year in plastics production and conversion processes (OECD, 2023).

Indeed, oil and derivates are a leading cause of global warming (Kweku et al., 2018), responsible for about one-quarter of the greenhouse effect (Gleckman, 1995). To meet the climate neutrality mission by 2050, EU countries are forced to decouple economic growth from oil extraction. In this regard, the so-called bioeconomy plays a pivotal role (Ronzon et al., 2022). Bioeconomy is "the economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources" (McCormick and Kautto, 2013). Converting biomass (e.g. crops, wood, energy plants, agricultural and forestry residues, municipal, industrial, and food wastes) into high-value end-products, such as food, bioenergy, biofuels, biochemicals, bio-based plastics (Yang et al., 2021; Mougenot and Doussoulin, 2022), the bioeconomy model seeks to substitute fossil carbon with bio-based carbon and uptake biogenic CO2 (Leiplod and Petit-Boix, 2018).

Although bioenergy and biofuels are the most advanced applications (Adamowicz, 2017; Nazari et al., 2021), an acceleration in R&D for innovative materials under the bio-based plastics umbrella has been recently noticed. Driven by the increasing awareness about marine littering (Gold et al., 2013), the legislative commitment toward circular economy (CE) (Foschi and Bonoli, 2019), the green purchasing trend (Filho et al., 2021; Moorthy et al., 2021) and the multiplying challenges affecting global supply chains (Arikan & Ozsoy, 2015), the production capacity of bio-based plastics is expected to increase from 2.12 million tonnes in 2022 to approximately 6.3 million tonnes in 2027 (European Bioplastics, 2022). However, while extant literature deeply scrutinises the influence of bioenergy and biofuels to climate neutrality, more is needed to know about bio-based plastics. Indeed, bio-based plastics refer to a large range of materials (see section 2.1.) that may provide reasonable solutions to many environmental concerns. First, bio-based plastics may contribute to decarbonization because of their lower carbon footprint compared to fossil-based counterparts (Boonniteewanich et al., 2014; Muhammad Shamsuddin, 2017; Philp, 2014; Piemonte, 2011; Spierling et al., 2018; Bishop et al., 2021). Second, when compostable, bio-based plastics may solve the challenges faced by waste recycling facilities with regard to food contamination and complex product design (Paletta et al., 2019). Finally, when biodegradable, bio-based plastics may represent a panacea for microplastic generation, ecotoxicity and marine pollution in general (Meereboer et al., 2020). Yet, it has to be noted that many issues are still open when considering the contribution of bio-based plastics to circularity and sustainability. As Bishop et al. (2021) pointed out, the lack of a holistic picture of the environmental impacts of bio-based plastic products makes LCA studies unreliable. As a result, Yan et al. (2021) highlight the risk of biased or misleading estimates of climate mitigation contribution.

Others have questioned the impact of bio-based plastics on resource preservation, as their production is still primarily based on virgin feedstock, thus creating pressure on natural ecosystems and increasing competition for land usage (D'Adamo et al., 2020; Imbert, 2017). In addition, the one-to-one substitution trend from conventional to bio-based plastics observed among converters could undermine the expected environmental benefits if the design process does not consider the specific conditions of use and disposal. Indeed, these materials may not foster the loop closing if consumers are not well informed about the proper disposal pattern, dedicated waste infrastructures are not established, advanced biotechnological recycling technologies are not developed and more in general, when heterogeneity and fragmentation continue to characterize waste governance across Europe (Rosenboom et al., 2022). Although the above-mentioned critics highlight that tighter integration between bioeconomy and CE is necessary (D'Amato and Korhonen, 2021), many additional concerns related to carbon sequestration, biodiversity, biodegradability in soil and marine environments and toxicology still exist and compromise the overall reliability of these materials (Nessi et al., 2021; Arantzamendi et al., 2023). As pointed out by the European Commission (2018b) in the Bioeconomy Strategy "To be successful, the EU bioeconomy needs to have circularity and sustainability at its heart". Translating this intent into the BBPs industry, the present work aims to investigate what hinders and enhances BBP materials' transition to a sustainable and circular bioeconomy. In line with Leipold and Petit-Boix (2018), this study mobilizes the business community and policymakers, addressing the following questions:

RQ1. What legislative, economic, social and environmental trends may affect the circularity and sustainability of BBPs?

RQ2. Which are the key strenghts and weaknesses detected by business players and able to accelerate and/or hamper the circularity and sustainability of BBPs?

With the final objective of providing recommendations and future orientations for a more sustainable circular bioeconomy in the BBPs value chain.

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Given that circularity depends on the system in which materials or products are distributed (European Environment Agency, 2017), the analysis was contextualized to European countries. System and life cycle thinking were adopted in line with sustainability and circularity principles. Moreover, multi-dimensional analysis was used to collect and intersect legislative, economic, social and environmental aspects, while multi-level examination (i.e. at system level and corporate level) supported the authors in identifying mutual impacts, moving from system dimension to business environment and vice-versa.

The paper is structured as follows: bio-based plastics value chain is reported in section 2, followed by research design and methodological framework (section 3). Findings from the system (section 4) and corporate (section 5) analysis are summarized in the discussion and conclusion sections.

2. Background

2.1 Plastics and bioplastics value chain

The term plastics reflects a wide range of materials, but it commonly refers to conventional plastics that are petroleum-based and degrade over hundreds of years. The term bioplastics, by contrast, still needs a valid and recognized definition. The term has been used to describe bio-based and/or biodegradable plastics, which has generated misunderstandings among scientists and consumers. Under this consideration, the European Commission started a massive informative campaign to recommend using specific terminology (Filho et al., 2021) that could reflect both sourcing and biodegradability properties.

Bio-based plastics are mostly derived from renewable resources (Álvarez-Chávez et al., 2012; DiGregorio, 2009) where the bio-based plastics content is determined by CEN/TS 16137:2011 standard. Commercially available bio-based and potentially biodegradable polymers are polylactic acid (PLA), polyhydroxyalkanoates (PHA) and starch blends (see Figure 1). As circularity, biodegradability is a system property (European Bioplastics, 2015) that flows from the environment in which the material degrades. Many factors influence the biodegradability of materials, including the type of microorganisms, the molecular polymers' structure, and the product design (Molenveld and Zee, 2020). So, degradation in aquatic systems involves physical, chemical and biological processes and mainly depends on water temperature and polymer shape (Volova et al., 2010); biodegradation in the soil is determined by the presence of bacterial biomass (Adhikari et al., 2016) while experimental conditions influence biodegradation in industrial plants (Thakur et al., 2018).

Figure I. Commercially available bioplastics

BIOPLASTICS		
Bio-based	**Bio-based and biodegradable**	**Biodegradable**
• BIO-PE • BIO-PET • PTT	• PLA • PHA • PBS • Starch blends	• PBAT • PCL

Source: Authors' elaboration

However, not all bio-based plastics are biodegradable. Bio-based non-biodegradable plastics include bio-polyethene (bio-PE), bio-polyethene terephthalate (bio-PET), and polytrimethylene terephthalate (PTT). Biodegradable plastics but fossil-based, such as polybutylene adipate terephthalate (PBAT) and polycaprolactone (PCL), are also considered bioplastics, but the use of this terminology is discouraged (Pellis et al., 2021) since their production is still oil-dependent.

In addition, renewability and biodegradability properties strongly affect the upstream and downstream sides of the existing plastics' value chain. Depending on the surrounding conditions, both properties can have a completely different characterization. While fossil-based plastics are mainly made in petrochemical refineries—where oil is subject to distillation, cracking, polymerization and blending processes—bio-based plastics are manufactured through either chemical processes (hydrolysis, dehydration, etc.) or biotechnological processes (fermentation, extraction, etc.) in biorefineries (Ubando et al., 2020). Based on the type of biomass used, bio-based plastics can be sourced from three different feedstocks: (i) 1st

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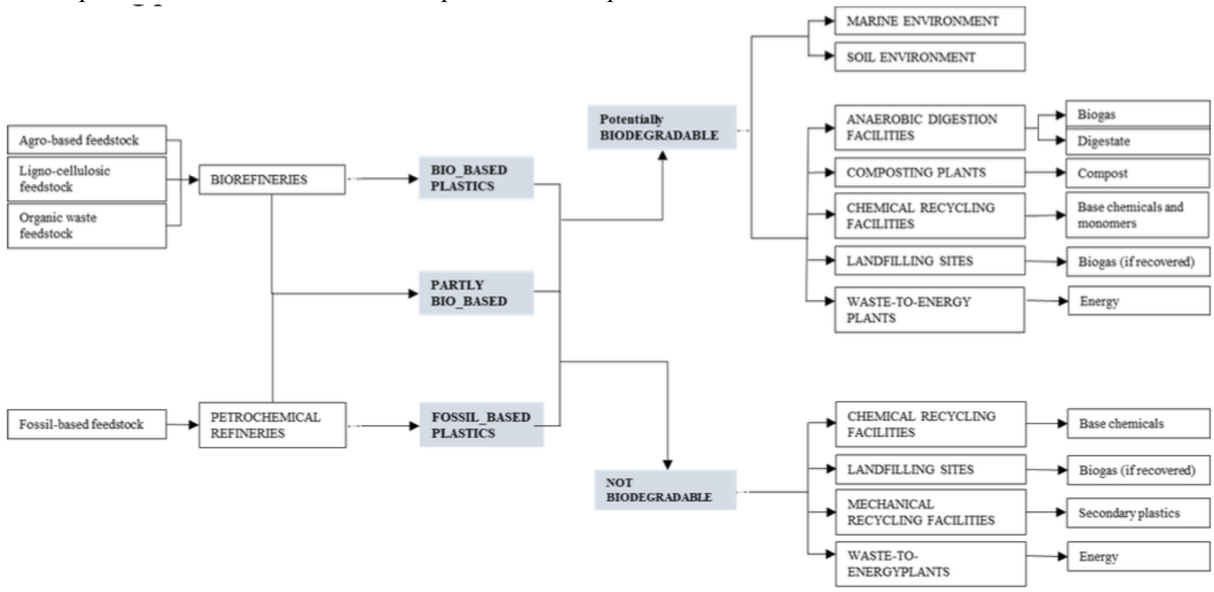
generation, such as corn or sugar cane; (ii) 2nd generation, which can be either non-food crops (e.g., cellulose) or agro-industrial waste; or (iii) 3rd generation, sourced from algal biomass, which has a higher yield than 1st and 2nd generation feedstock. Today, most bio-based plastics derive from crop-based feedstock (Philp, 2014), while the 2nd generation is available in small volumes, and the 3rd is still in early development.

Figure 2. Upstream and downstream sides of plastics and bioplastics



Source: Authors' elaboration

The end-of-life (EoL) opens the doors to a variety of waste management scenarios (See Figure 2), leading to first distinguishing controlled and uncontrolled environments. Industrial-scale facilities monitor and manage material recycling or energy recovery performances with the former. Meanwhile, the latter generally refers to an open environment, mainly soil and marine ecosystems (European Environmental Agency, 2018; Karan et al., 2019). Notwithstanding that existing ISO 17556 and ASTM D5988 provide criteria for the biodegradability of plastics in soils only and a standard for biodegradability in marine environments is under discussion (European Commission, 2022), recent studies bring into discussion the validity of these standards outside of laboratory conditions which on one side do not reflect what is commonly expected in a natural environment and, on the other, do not capture the extreme variation of natural conditions (Emadian et al., 2017; Briassoulis et al., 2017; Harrison et al., 2018; Di Bartolo et al., 2021).

Although BBPs are mainly incinerated or landfilled today, mechanical, organic and chemical recycling are the preferred EoL options in controlled environments (Ramesh Kumar et al., 2020). Mechanical recycling is suitable for the management of the drop-ins (bio-PE, bio-PET, bio-PTT, etc.) since they have the same chemical composition as their fossil-based counterpart, which are widely present in Europe for the treatment of traditional plastic waste streams (Paletta et al., 2019). Organic recycling theoretically treats bio-waste streams with compostable and biodegradable plastics certified by the European EN 13432, EN 14995, or the international ISO 17088. Organic recycling infrastructures include anaerobic digesters and/or composting plants (Carlini et al., 2017). Another emerging scenario is chemical recycling, which is based on hydrolysis, alcoholysis, glycolysis, aminolysis and ammonolysis (Lamberti et al., 2020) and allows the extraction of high-value chemicals/monomers from different biopolymers. However, chemical recycling infrastructures need to be well-established in Europe, slowed down by the high costs of depolymerization (Di Bartolo et al., 2021).

2.2 Bio-based and biodegradable plastics in the context of sustainable circular bioeconomy

CE is a system where the value of products, materials and resources is maintained in the economy for as long as possible while waste generation is minimized (European Commission, 2018a). In other words, CE is an economic system where the

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EoL concept is replaced with production, distribution and consumption processes that reduce, reuse, recycle, and recover materials in service of sustainable development. As less dependent on oil, bioeconomy is perceived as an opportunity to mitigate climate change while sustaining economic growth and human well-being (Phil et al., 2018). However, combining CE with bioeconomy has prompted reflections on the circular bioeconomy. Indeed, while CE and bioeconomy definitions are trending among practitioners and academics (Kirchherr et al., 2017), circular bioeconomy has yet to be fully explored in the literature. Even so, the residual research stream dealing with circular bioeconomy reveals conflicting opinions on the interlinkages between the two economic models: while some authors consider the bioeconomy to be "circular by nature" (Sheridan, 2016), others express concerns about the risks of following a linear business-as-usual approach (Bezama, 2016; Stegmann et al., 2020; Tan and Lamers, 2021). The most recognized definition comes from Stegmann et al. (2020), who defined the circular bioeconomy as "an economic model in which bioresources are used to make products with the highest possible added value in a sustainable way, with a cascaded use of materials and minimizing resource inputs and outputs to the natural environment". In line with the biological cycle of Ellen Mac Arthur Foundation's butterfly diagram, circular bioeconomy emphasizes the use of renewable resources, cascading the use of biomass and reintroducing biological nutrients in the biosphere (Ellen Mac Arthur Foundation, 2019; Karan et al., 2019). Applying this concept to bioplastics, only BBPS, and consequently, compostable plastics, have the potential to circulate and recirculate in that cycle. From this, we can surmise that BBPs are:

H1. Circular when added value is created and retained in further production and consumption cycles.

H2. Sustainable when natural resources are not depleted and environmental impacts are minimized.

Unfortunately, the analysis along the value chain reveals the emergence of a take-use-dispose model characterized by virgin biomass supply in the upstream stage and immature EoL scenarios downstream. Since existing circularity and sustainability metrics are still at the infancy stage for these applications (Bishop et al., 2021; Chioatto and Sospiro, 2022; European Commission, 2018b; Yates and Barlow, 2013), results are often contradictory and, consequently, inconsistent. Moreover, the integration of economic, social and environmental impacts needs to orientate decisions towards a sustainable circular bioeconomy (Blum et al., 2020; Rosenboom et al., 2022). It follows that a major interplay between the circularity and sustainability of BBPs needs to be investigated. To do that, a better understanding of what sustainable circular bioeconomy pragmatically means in the BBPs industry is necessary.

3. Method and materials

3.1 Research design

To scrutinize the circularity and sustainability of BBPs, the research design has been informed by a combination of life cycle and system thinking. Life cycle thinking is crucial in CE studies to assess the impacts of materials, products or services from raw materials supply to EoL and make evidence of closing, narrowing or slowing resource loops (Heiskanen, 2002). Instead, system thinking is commonly used in sustainability transition theories (Barbier and Burgess, 2017) to understand how different parts of the system where firms operate are interrelated and evolve over time. Multi-dimensional analysis contributed to examining system dynamics from multiple domains (Meadows, 2009). Coherently, multi-level investigation supported better identifying relationships between macro and micro levels. Macro-level analysis has been conducted through a literature analysis of legislative, economic, environmental, and socio-cultural trends characterizing BBPs. Micro-level analysis has been advanced through the realization of semi-structured interviews with the key players of the bio-based plastics industry, including EU material suppliers, converters, end-users and waste managers.

3.2 Data collection and elaboration

Precisely, a literature analysis was performed to reconstruct the legislative roadmap that framed the bio-based plastics industry and gathered qualitative and quantitative data on the market and community behaviours. Then, an empirical analysis was run to collect insights at the corporate level by directly engaging business players. In total, 40 key players operating in the European market were invited by e-mail to participate in the research. Specifically, the top five market players were

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invited for each stage of the value chain. Per each company, the sustainability or product manager was interviewed. The interview protocol is reported in Appendix I. Each interview lasted for about one hour on average. Interviews were recorded, transcribed and manually coded. Two researchers always participated in the interviews and jointly performed the text analysis to increase reliability.

Then, secondary data collected through a desk research of scientific papers, policy documents and research outcomes published by organizations outside of the traditional academic communication channels (i.e., the so-called grey literature), were intersected with the primary data obtained from interviews to get insights on the key elements driving a sustainable circular bioeconomy in BBPs value chain.

4. System analysis: existing trends in the European bio-based biodegradable plastics industry

4.1 Normative and legislative perspective

The establishment of the EU Strategy for Bioeconomy in 2012—and its revisions in 2018—have served as a roadmap for European economies (Ronzon et al., 2022). Compared to the first version, the updated statement shows a better integration of environmental, economic and social aspects by promoting local bioeconomies and ensuring that the same legislative and financial efforts are applied to all sectors, including bio-based plastics (Ronzon and Sanjuán, 2020). This new approach has prompted European countries to build up their own orientations for a sustainable and competitive bioeconomy in Europe (Bracco et al., 2018; McCormick and Kautto, 2013).

Concerning bio-based plastics, the key EU policy document is the Circular Economy Action Plan and its updated version published in 2020 that still allocates resources to these materials through a focus on sustainable sourcing and standardized labelling schemes (European Commission, 2021). As part of the Green New Deal, this intention is operationalized in a public consultation aimed at examining the sustainability of the feedstock as well as the role of biodegradability and compostability in specific environments. From the legislative point of view, the Directive 2015/720 (European Commission, 2015) has compelled a solid push for the BBPs market by introducing a progressive elimination of very lightweight plastic carrier bags and a transition to biodegradable and compostable single- use bags and long-life reusable bags (Foschi and Bonoli, 2019). Furthermore, the Directive 2018/851 allocates attentions to EPR schemes and their role to foster shared responsibility among packaging users, consumers and recyclers but their scope should be extended to industries (European Commission, 2018b).

Almost simultaneously, the Directive on Single-Use Plastics (SUP) introduced market restrictions to reduce the consumption of certain categories of SUPs like straws, plates, cutlery, food containers, beverage containers and beverage cups (EU Directive 2019/904). Alongside the market-based instruments, legislators introduced a plastics tax in 2021 on non-recyclable plastic packaging waste (European Commission, 2020) to accelerate reusable, recyclable and compostable plastic packaging, as promoted by the European Strategy for Plastics in a Circular Economy (European Commission, 2015). The recent policy framework on bio-based, biodegradable and compostable plastics sets out the conditions that have to be met to ensure overall positive environmental outcomes from the production and use of these plastics, including a) supply of sustainable feedstock; b) use of bio-based plastics in long-lived products; c) use of plastics that biodegrade in open environments only wherein applications and contexts where the full biodegradability has proven under specific real, local conditions and timeframe; d) use of compostable plastics only in applications and contexts where a compatible waste collection and treatment system is in place (European Commission, 2022).

A comprehensive overview of the normative aspects is summarized in the following Figure.

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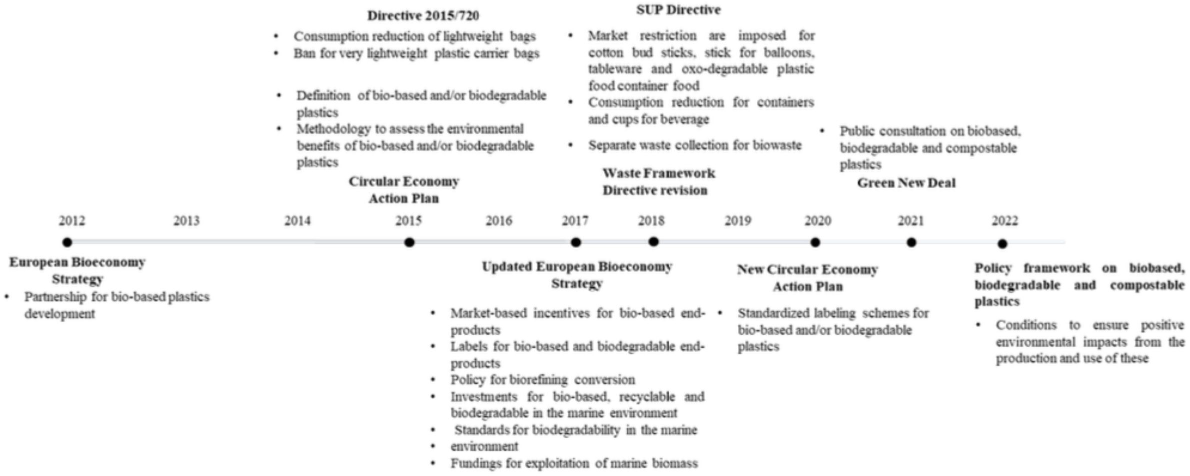
Figure 3. Relevant EU policies affecting the BBPs industry



Source: Authors' elaboration

4.2 Economic perspective

According to the statistics published by European Bioplastics (2022), the 2022 European bioplastics demand can be estimated at slightly more than 2.2 Mt, with a slight prevalence of bio-based and biodegradable compared to the non-biodegradable ones. Indeed, bio-PE, BIO-PA and bio-PET and PTT contribute to 48% of the total share. Besides the competition with r-PET, only a few beverage companies such as Coca-Cola, Pepsi and Nestle have launched bio-based bottles to the market (Lamberti et al., 2020). Among the biodegradable fractions, PLA, PHA, and starch blends are the most demanding biopolymers, accounting for 52% of the total share in 2022 (European Bioplastics, 2022). Even if these blends are predicted to increase in the following years, one of the most challenging elements characterizing the market of biodegradable and compostable plastics is the limited availability of the materials due to the small production capacity and the difficulties of reaching economy-of-scale. Indeed, about 20 compounding sites are active in Europe, some of which have multiple value propositions. They are generally backwards-integrated on intermediates and even base chemicals, while some are downward-integrated on manufacturing semi-finished and finished goods. Because of this situation, there are difficulties in collecting and sharing official data (Castellano, 2018). However, among the leading companies, only a small-scale PLA polymerization plant is located in Europe while the key player is NatureWorks LLC, with a manufacturing facility in Nebraska and a new site in Thailand, expected to be ready by 2024 (PlasticConsult for Assobioplastiche, 2020). The European output of thermoplastic starches (TPS) is estimated at over 200,000 tons in 2019, with the highest capacity detected by Novamont, recently acquired by Eni-Versalis, followed by minor Dutch and German companies (PlasticConsult for Assobioplastiche, 2019 and 2020). PHA is not commercially available in Europe, but nearly 50% of the global production (estimated to be less than 100,000 tons) comes from Metabolix, Danimer Scientific and RWDC Industries, whose production sites are in USA and Singapore (Rosenboom, 2022).

4.3 Social perspective

About the circularity of BBPs, end-users and consumers play a crucial role in preserving the intrinsic value of BBPs, especially during consumption and disposal patterns. Driven by the increasing awareness about the impact of plastics in worldwide oceans, consumers' attitudes toward the proper use of plastics are massively growing. Filho et al.'s (2021) survey of 16 European countries revealed that 74% of respondents segregate plastic waste and dispose of it properly in specific containers, per their country's regulations. However, compostability and biodegradability properties are still confusing

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(Lynch et al., 2017). Moreover, the distinction between conventional plastics and BBPs for consumer packaging largely challenges European and international consumers (Dilkes-Hoffman et al., 2019).

Several studies have examined the general influence of consumers' sociodemographic characteristics on the green purchasing trend (Reinders et al., 2017). The study by Klein et al. (2019) revealed that gender, age and education do not influence the purchase intention or bioplastic products; instead, values, attitudes, product experience and interest in information have the strongest impacts. Several previous studies have identified a clear link between consumer psychological traits such as attitudes, perceptions and motivations, and consumer acceptance of alternative plastics such as those that are bio-based or biodegradable (Fletcher et al., 2021, Barbir et al., 2021, Filho et al., 2022, Stasiškienė et al., 2022).

4.4 Environmental perspective

Although BBPs are perceived as more environmental-friendly compared with conventional plastics (European Commission, 2022), robust scientific evidence still needs to be included. Existing LCA studies need to be more comprehensive regarding methodology, data source and results, making comparability difficult. If cradle-to-gate studies laid down on the uptake of biogenic carbon through the feedstock, the GHG-emissions profile is acute when considering EoL, Comparative cradle-to-grave study analysed by Spierling et al. (2018) on eight bio-based and conventional plastics shows negative impact categories for the first compared with the second, mainly due to energy consumption during the waste management (Hottle et al., 2017). Moreover, EoL impacts are difficult to estimate because of the lack of traceability for compostable and biodegradable plastics today and, at the same time, the lack of estimation about biodegradability performance of different biopolymers in different environments first, and the impacts of biodegradation processes on the environment and human health then. Additionally, most of the studies are based on examining the global warming potential impact category, underestimating other relevant impacts such as land use, water use and biodiversity (Di Bartolo et al., 2021).

5. Corporate analysis: strengths and weaknesses influencing the sustainability and circularity of the bio-based and biodegradable plastics value chain

Data collected from the semi-structured interviews allowed the researchers to move from the system to the corporate level and identify strengths and weaknesses influencing the sustainability and circularity of the bio-based and biodegradable plastics value chain. Sustainability and circularity are values that have pushed firms to invest in the sector (see Table 1). However, challenges (see Table 2) remain predominant and must be addressed. Findings are categorized by a group of actors to let emerge their different perceptions in the value chain.

Table 1. Strengths points emerged among the actors of the BBPs value chain

Interviewees	BBPs allow to.../are attractive because....
Material suppliers	• "offering new solutions where renewability and biodegradability are value-added (e.g. mulch films)" • "being recognized as innovative and green" • "increasing interest among our customers in offering green end-products" • "use of EU funds that are more oriented to BBPs" • "acquisition of existing non-efficient or obsolete petrochemical plants that are converted to the bio-chemistry" • "use of marginal land for crops that are low-water dependent" • "with certification it is possible to attest compostability" • "cooperation with different actors of the value chain that increase intangible capital" • "allow the use of 2nd generation feedstock by valorizing lignocellulosic waste streams" • "create multiple value along the entire value chain that can be demonstrated with the use of life cycle-based tools" • "increasing cooperation with organic waste treatment plants to solve technical challenges at the EoL"

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Converters	• "major inclination toward BBPs because it is the most eco-friendly solution" • "differentiate the product offer" • "with BBPs it is possible to provide tailored solutions, often associated with consulting or training service" • "entering new markets" • "no need of high investments in machinery due to the possibility of processing to process BBPs in the same machinery where conventional plastics are transformed" • "use of innovation labs to co-design and test new materials and applications" • "new collaborations with suppliers and new partners to manufacture high-performance products"
End users	• "customers and society at large have a rising need for greener end-products" • "proliferating interest toward compostable food packaging among brand owners" • "increasing interest toward eco-friendly and bio-based reusable goods" • "create partnerships with upstream players of the value chain to tailor and customize the solutions" • "increasing trend of green public purchasing"
Waste managers	• "strengthen the local closed-loop supply chain to reduce disposal costs" • "closed collaboration with materials suppliers to test compostability and biodegradability performance and provide feedbacks to converters on product eco-design" • "creation of networks working on specific waste streams"

Source: Authors' elaboration

Table 2. Weakness points emerged among the actors of the BBPs' value chain

Interviewees	**BBPs are hampered by …**
Material suppliers	• "small production capacity and difficulties in reaching economies of scale" • "difficulties in investing in other countries because of the lack of harmonized policy and orientations across Europe" • "difficulties in supplying a high volume of bio-waste to experiment with 2nd generation feedstock and so, minimize the purchasing costs of virgin feedstock, reduce the land occupation and decrease competition with food" • "need to make very large investments in R&D" • "high transportation costs of raw materials to the biorefineries and emissions to transportation" • "high production costs" • "lack of knowledge among stakeholders about the implications of biodegradability properties" • "lack of skilled workforce" • "need for more clusters focusing on bioplastics that allow dialogue between different subjects like institutions, companies, universities, and research centers" • "necessity to make policymakers aware of the lower total cost of ownership, i.e. the cost for the system related to BBPs vs. fossil-based plastics"

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Converters	• "discontinued materials supply" • "increasing competition because of the higher demand for bioplastics from high-value industry (e.g., medical, cosmetic)" • "challenging export because of different legislation and waste governance." • "agitation derived by the measures imposed by the SUPs Directive" • "investment on compostable tableware that is now banned by the SUPs Directive" • "insufficient performance of BBPs for certain applications" • "continuous need for higher R&D capabilities to improve BBPs' performance" • "high testing costs for EoL performances"
End users	• "lack of efficient labelling scheme for better communication to the consumer" • "high testing costs for contamination and health security issues (especially in the food sector)" • "effort in understanding the different EoL scenarios in place in exporting countries (e.g., home composting is different from industrial composting)" • "hostile disposition among consumers toward BBPs because of the food competition, the land occupation and the use of virgin feedstock" • "customers' skepticism and/or preference for other materials, like paper, wood, algae, etc." • "increasing customer orientation toward reusable applications" • "efforts in communicating the properties of the end-products and implications on consumption and disposal patterns"
Waste managers	• "lack of harmonized waste treatment that is municipality- and country-oriented" • "lack of adequate waste management plants to treat BBPs" • "inefficiencies of lab-scale compostability tests • "difficulties of composting rigid products in composting plants"

Source: Authors' elaboration

6. Discussions and concluding remarks

Key interesting findings emerge from the analysis of trends detected at system level with the perceptions collected 'from the bottom' by interviewing value chain actors (Table 3). Several elements contribute to the uptake of BBPs; opportunities emerge from legislative/EU policy, economic trends, socio-cultural changes and environmental aspects. However, the same domains also embedd challenges that migh hinder the diffusion of BBPs that really contribute to circularity and sustainability.

A key element seems necessary to foster BBPs: collaboration along the value chian. Results reveal that despite being recognized as innovative and green when using BBPs, material suppliers understand the potential to collaborate along the value chain to use alternative biological feedstock, with the resulting valorization of local economy and rural areas. However, no attention is currently paid to waste collection and valorization. Looking at the conversion stage, value is generally captured in biowaste bags, food packaging and agricultural mulch films and collaboration is basically fostered to improve technical and mechanical performances. Nevertheless, increasing interest is detected among end-users and brand owners intensively for using BBPs in durable products. Actors operating in waste management call for collaboration to test compostability and biodegradability performance in real other than lab conditions, thus trying to reduce the cost of uncompostable waste in composting facilities.

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Table 3. Value-chain based and multi-faceted SWOT analysis

	Legislative perspective	Economic perspective	Social perspective	Environmental perspective
S	Identification of end-products where BBPs may create added value	Exploitation of local and integrated supply chain based on the valorization of agro-industrial waste	Increasing awareness about marine plastic pollution	Compostability and biodegradability for specific applications
W	Lack of clear policy orientations	High price of bio-based plastics compared with the conventional ones	Lack of clear labeling scheme for BBPs and relative disposal patter	Dependence of biodegradability and compostability performances from applications and contexts
O	Introduction of EPR scheme to manage compostable plastic applications across Europe	Public funds for new integrated biorefineries	Increasing green purchasing trends	Renovation and/or introduction of new standards and eco-design guidelines assessing compostability, biodegradability, and more in general circularity
T	Market bans on end-products made of BBPs	Introduction of the plastic tax	Skepticism behaviors and confusion among consumers	Lack of clear criteria to perform LCA analysis

Source: Authors' elaboration

More broadly, results reveal the urgency to develop a combined CBE strategy to capture and retain multiple values from biological resources. Specifically, dedicated roadmaps should be established for each end-product, including BBPs.

From the legislative point of view, well-defined waste governance with a dedicated EPR scheme would facilitate better value retention from bio-based, biodegradable, compostable but also mechanically recyclable plastics.

From the social point of view, end-users and consumers should be better informed about the proper disposal of bioplastics, especially when compostable. Harmonised labelling schemes facilitating consumers' choices and robust, informative campaigns stimulating demands are envisaged. To reduce scepticism among end-users, customized solutions that match the local conditions should be pursued case-by-case, especially for applications involving biodegradation in open environments.

From an economic point of view, it is essential to develop an integrated and local supply chain to address the limited production capacity and, consequently, the high costs of raw materials supply. When the supply chain is based on symbiotic exchanges of residues among local farmers, it can also push the identification of valuable resource streams to valorize into 2nd generation feedstock while reducing the demand for pesticides, land and water to cultivate virgin biomass, thus contributing to more circularity and sustainability. The need to increase production capacity can be stimulated by investing in brownfield sites, thus providing an additional boost to the local economy and reducing the risk of land availability exacerbation.

From the environmental point of view, since the key issues are detected at the EoL, new eco-design guidelines and EoL standards need to be provided and/or revised. It is possible by enforcing formulations that tailor the degradation timescale according to the products' purpose and expected life. Eco-design guidelines can support identifying the correct application that, in line with circularity goals, can regulate the conversion processes. At the same time, the tendency to use BBPs in durable products creates boundary conditions for a user-centric chain where lifetime extension strategies, like reuse, repair and refurbishment, can be exploited. Standardised eco-design and strict EoL measurement criteria may support the establishment of a harmonized LCA methodology for these materials, thus stimulating comparability and benchmarking.

To sum up, our study shows that although BBPs are generally considered more environmental-friendly than conventional plastics, robust scientific evidence on their impacts compared to fossil-based plastics is still missing. The lack of tools and metrics to assess the circularity and sustainability of BBPs industry poses relevant challenges for its upscaling and contribution to climate neutrality goals in Europe. It calls for the adoption of system and life cycle thinking, guided by multi-level (system and corporate) and multi-dimensional (legislative, social, economic and environmental) analysis, which led

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researchers to build a comprehensive picture of trends, gaps and future orientations that may boost a sustainable circular bioeconomy in the sector.

To the authors' knowledge, the paper is the first to discuss the value of BBPs in the broader sustainable circular bioeconomy model. Specifically, the paper makes several contributions to the bioplastics discourse. From the research point of view, it identifies the key area of investigation that needs to be explored in further research agenda. Specifically, 4x4 significant topics have been identified for theoretical underpinnings. Managerial implications include a list of recommendations for EU policymakers for an integrated circular bioeconomy strategy aimed at (i) adding value to BBPs through alternative raw materials supply, (ii) retaining value through reuse and recycling, (iii) ensuring lower environmental impacts through cross-sector collaboration and well-functioning waste governance.

Data availability statement

The datasets generated during and/or analysed during the current study are not publicly available due to their confidential nature but are available from the corresponding author upon reasonable request.

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Appendix

1. PRESENTATION QUESTIONS

A. Please provide a brief description of the company: what is its business? what type of plastic resins (in general) does it use?

2. QUESTIONS ON HOW, WHEN, WHY IS A MATURE DECISION THE INTRODUCTION OF BIOBASED MATERIALS

B. Do you use compostable biopolymers according to the norm EN 13432: 2002? Do you use compostable biopolymers from renewable sources?

C. When and why did you introduce bio-based plastics in your product/ process/product line? (interviews were prompted to indicate opportunities detected, main motivations, customer requests, etc)

D. What were the problems or obstacles that generated doubts about the technical feasibility and/or economic feasibility of starting using bioplastics? How have these issues been overcome?

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