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Article

The Role of Simulation and Serious Games in Teaching Concepts on Circular Economy and Sustainable Energy

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Abstract: The prevailing need for a more sustainable management of natural resources depends not only on the decisions made by governments and the will of the population, but also on the knowledge of the role of energy in our society and the relevance of preserving natural resources. In this sense, critical work is being done to instill key concepts—such as the circular economy and sustainable energy—in higher education institutions. In this way, it is expected that future professionals and managers will be aware of the importance of energy optimization, and will learn a series of computational methods that can support the decision-making process. In the context of higher education, this paper reviews the main trends and challenges related to the concepts of circular economy and sustainable energy. Besides, we analyze the role of simulation and serious games as a learning tool for the aforementioned concepts. Finally, the paper provides insights and discusses open research opportunities regarding the use of these computational tools to incorporate circular economy concepts in higher education degrees. Our findings show that, while efforts are being made to include these concepts in current programs, there is still much work to be done, especially from the point of view of university management. In addition, the analysis of the teaching methodologies analyzed shows that, although their implementation has been successful in favoring the active learning of students, their use (especially that of serious games) is not yet widespread.

Keywords: circular economy; sustainable energy; simulation; serious games; higher education

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1. Introduction

The role of universities in the actions that can be developed to mitigate climate change has been recognized for more than 60 years now [1]. Engineers, managers, politicians, and other professionals—who are trained in universities—are expected to be the precursors of a social change that leads us towards a more sustainable and efficient use of natural resources. However, many authors point out that higher education (HE) institutions, despite having introduced academic content in their programs, have not clearly supported the need for the shift from a linear economy (produce-use-dispose) to a circular one (produce-use with moderation-recycle and re-use). In the face of the climate crisis that we are experiencing, it is necessary that universities take a more predominant role in educating the new generations of managers, engineers and professionals with the skills and the values to deploy a circular economy (CE) and a more sustainable use of energy [2]. Authors such as Kopnina and Blewitt [3] reaffirm the fundamental role of HE institutions as key drivers in the change towards more more sustainable business practices. In addition, universities should act as sterling organizations where sustainability concepts are applied [4]. In summary, HE institutions become a key agent in fighting against the climate change, since they are the ones that can educate citizens in a series of methodologies, skills, and capacities that will led our societies towards a more environmentally friendly and socially sustainable future.

In this regard, education for sustainability is a concept that aims at preparing higher-education students with the skills and knowledge required for a transition towards a more sustainable business model [5]. Going a step further, education for environmental sustainability prepares students to develop their activity by recognizing the complexity of environmental problems and educating them in critical thinking with environmental strategies in mind. Among the contents that stand out the most in the new study programs are those related to the CE and sustainable energy [6–9].

Despite the critical role of the university in educating the future generation of leaders, there is a lack of literature discussing the teaching of circular economy and sustainable energy at HE institutions. This paper aims at analyzing the role of HE institutions in the generation of more CE-oriented and sustainable-driven professionals, and how simulation and serious games can contribute to achieve this goal. Altogether, the paper provides insights on trends and open challenges, which also become research and teaching opportunities for academics and practitioners. The remainder of the paper is structured as follows: Section 2 presents a description of the present research landscape in the field of circular economy and sustainable energy, with a focus on the area of simulation and serious games with learning purposes. Section 3 offers a brief review on the concepts of circular economy and sustainable energy. Section 4 highlights the role of simulation-based learning (SBL) in teaching the aforementioned concepts and values in higher education. Section 5 provides a similar discussion but focusing on serious games, which can be tremendously illustrative for educating the managers of the future. Section 6 describes a case study regarding the use of simulation-based education to enhance the efficiency of different business systems while also considering sustainability dimensions. Finally, Section 7 aims at providing an overview of the main trends and open challenges regarding the teaching of circular economy and sustainable energy concepts and principles to our students. This section also highlights the main conclusions of our work.

2. Research Landscape

This section contextualizes the present work by providing an updated picture of the research landscape in the field of CE and sustainable energy, with a focus on the area of simulation and serious games with learning purposes. There is a clear growing trend in the number of scientific publications in both fields, as shown by Figure 1, which depicts the evolution of Scopus-indexed articles that include the terms “circular economy” or “sustainable energy” in their title, abstract, or keywords (T-A-K) sections.

Figure 2 displays Scopus-indexed journals with four or more articles, including the combination of words (“circular economy” or “sustainable energy”) and “education”. Notice that the Journal of Cleaner Production, the Sustainability journal, and the International Journal of Sustainability in Higher Education seem to be the main references in this area, with several energy-related journals also included among the ones with more published documents on the aforementioned concepts.

Interestingly, an important portion of these publications pay attention to the education of CE and sustainable energy. More precisely, 18% and 20% of the articles published in the last ten years focus on educational aspects in the areas of CE and sustainable energy, respectively (Scopus-indexed articles with “circular economy” or “sustainable energy”, and “education” or “learning” or “teaching” in their T-A-K). The sustainable energy community identified relatively soon the advantages that simulation-based learning and serious games could bring to educational programs. A total of 23% of the publications dealing with educational aspects discussed any of these two approaches in 2011, reaching a significant 68% in 2020. Besides, the Internet is used as a vehicle to promote sustainability through learning simulations as well as serious games. For instance, the reader is referred to the non-profit Games4Sustainability platform (https://games4sustainability.org, accessed on 20 February 2021), where more than 100 simulations and games can be found. In the case of CE, the first articles exploring the use of simulation-based learning and serious games in the teaching activities appeared in 2013. After that, these tools have not attracted so much attention, with only an average of 19% of the teaching-related articles in this area dealing with any of these two approaches.

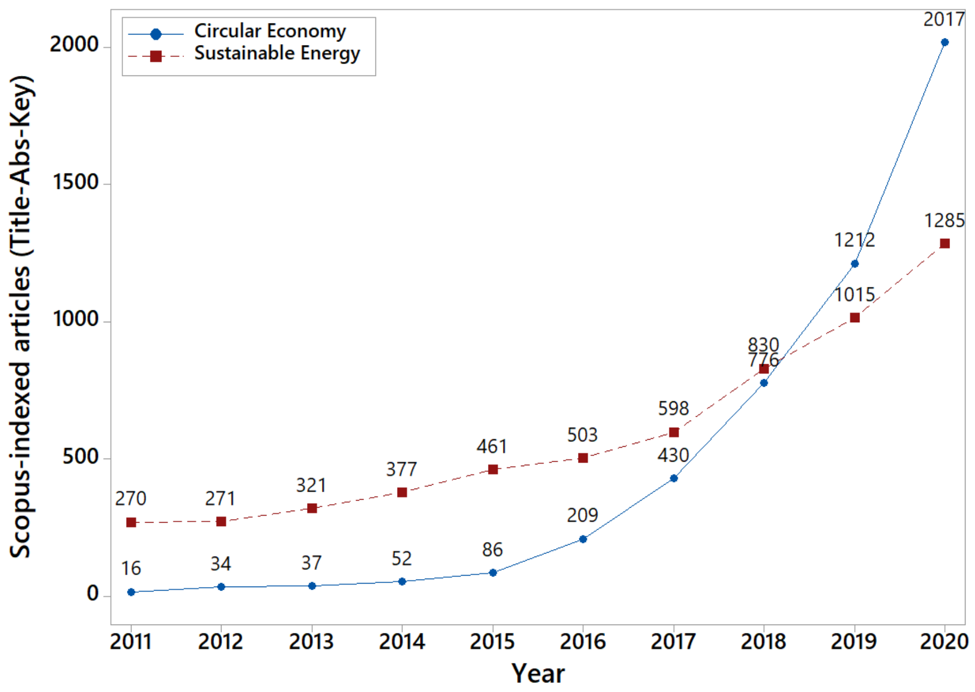

Figure 1. Scopus-indexed articles including "circular economy" or "sustainable energy" in T-A-K.

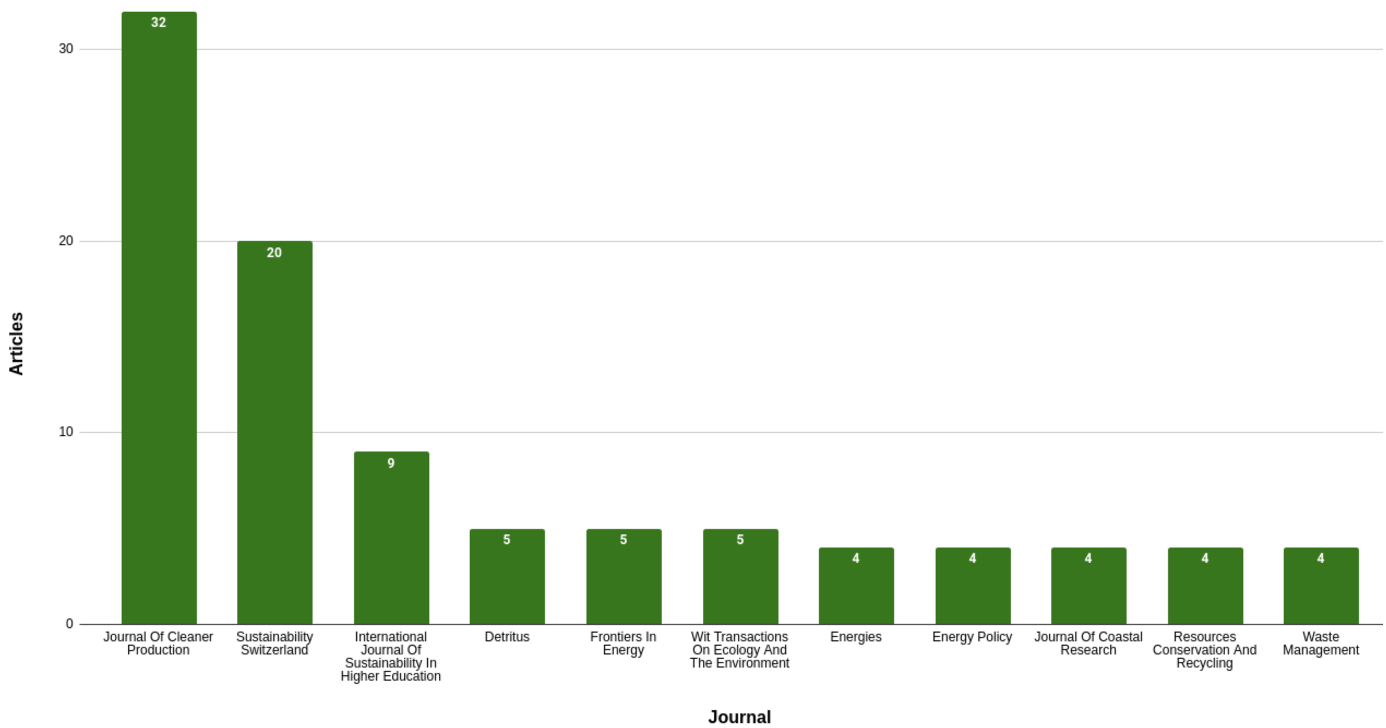

Figure 2. Relevant Scopus-indexed journals in the areas of education, CE (circular economy), and sustainable energy.

To analyze the evolution of simulation-based learning in these fields, the number of papers in Scopus-indexed journals searched using keywords "circular economy" or "sustainable energy" and "simulation" in the title, abstract and keywords, is displayed in Figure 3. The results show that the application of simulation in CE, although increasing, is lacking behind the application of simulation in sustainable energy. Not surprisingly, we have noticed the lack of research in the CE education at HE level that uses simulation-based learning, which we will discuss in Section 4.

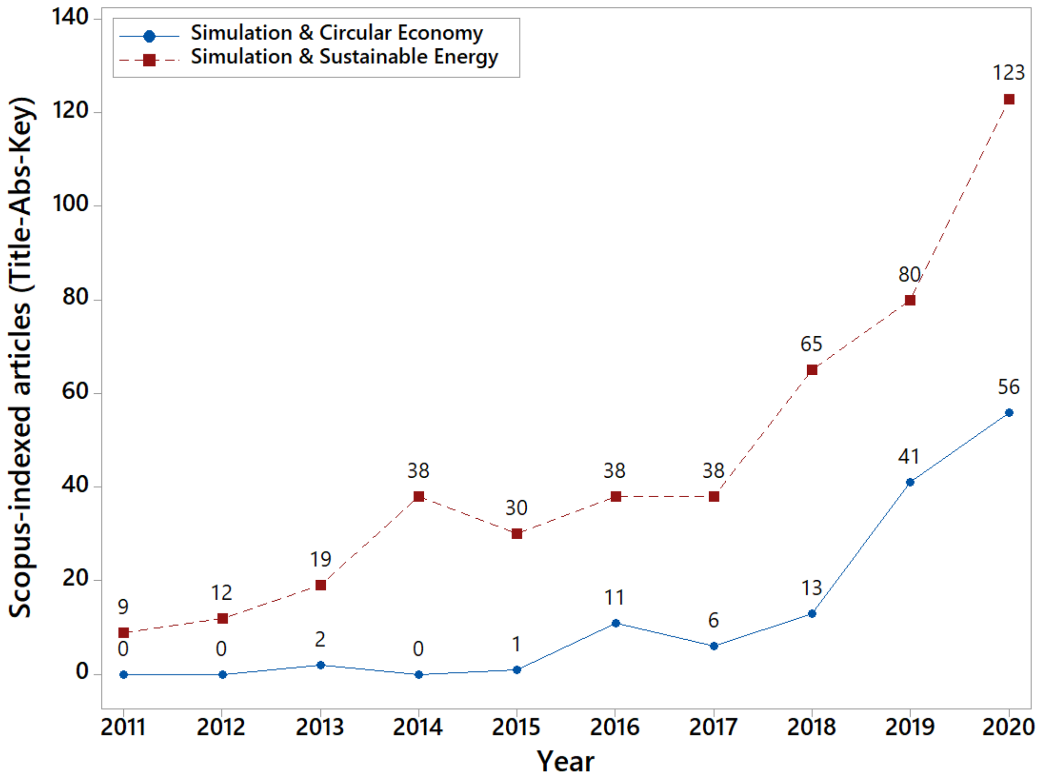

Figure 3. Scopus-indexed articles including "simulation" and ("circular economy" or "sustainable energy") in T-A-K.

In terms of serious games, as Figure 4 illustrates, despite the advantages that this teaching approach can bring to the field (see Section 5), the number of indexed publications regarding serious games addressing the topics of sustainable energy and CE is rather scarce—notice that this figure refers to all indexed documents, not just articles as in the previous ones. This scarcity of documents can be explained by the relative novelty of serious games in learning environments, which is accentuated by the novelty of the very concept of CE. Nonetheless, there is a presumably growing trend.

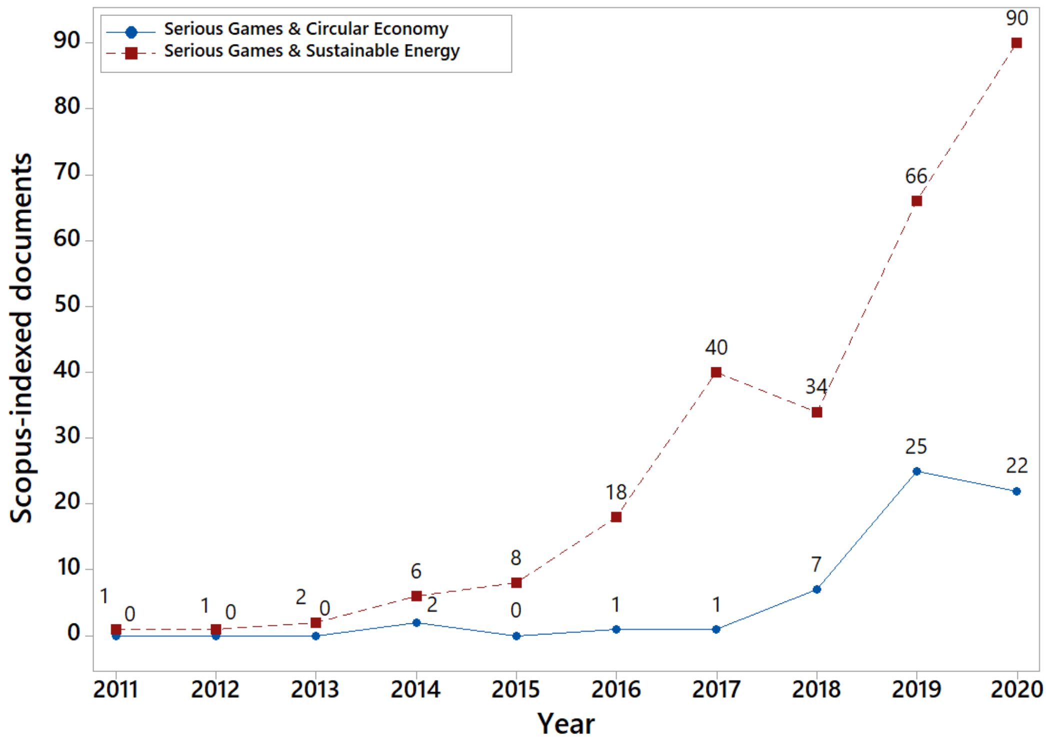

Figure 4. Scopus-indexed documents on "Serious Games" and ("Circular economy" or "Sustainable energy").

3. Literature Review

We have divided this review section into two parts. In the first one, we discuss recent work on the circular economy concept. In the second one, we provide an overview of recent articles related to sustainable energy principles. Of course, both concepts are strongly correlated, and we establish the corresponding connections between them during our analysis. As a result of this review, we have been able to generate Figure 5, which summarizes the teaching methodologies required, the disciplines that must be considered, and the main concepts that should be included in HE curricula oriented to promotion of sustainability issues.

3.1. Circular Economy

Circular economy builds on the concepts of eco-efficiency and eco-effectiveness [10]. Eco-efficiency refers to the delivery of goods and services to enhance human beings' lives while reducing environmental impacts inline with the Earth's carrying capacity [3]. Eco-effectiveness, on the other hand, starts with the desirable outcomes of products and systems and implements a strategy to achieve that outcome [11]. Although circular economy is related to these two concepts of eco-efficiency and eco-effectiveness, the concept of circular economy is still vague. Korhonen et al. [12] try to provide a more formal definition of this concept and to identify the main challenges associated with it. According to them, CE can be defined as an environmentally friendly economy that limits the production flow to a sustainable use of natural resources and energy. Recycling practices play a fundamental role in such an economy, hence generating a circular flow of production-consumption-recycling. Prieto-Sandoval et al. [13] also try to reach a consensus on the definition of the CE concept, which includes aspects such as a re-circulation of energy and resources, society needs, etc. These authors also perform a quite complete literature review, from which they offer some examples of CE actions implemented in different countries. These actions cover several sectors, and might refer to changes in business models, networks, organizational structures, processes, products, and services. In a similar attempt to clarify the CE concept, Kirchherr et al. [14] review existing uses of the term and conclude that most authors limit the concept to the reduction, re-cycle, and re-use of goods, without directly discussing the impact of current consumption models on sustainable factors, such as the quality of life of future generations, social equity, etc. Stahel [15] conceptualized CE as re-cycling or re-using goods once the normal life cycle is over, so that others can benefit from them instead of just generating new waste for society. This author emphasizes that just a few countries and regions—South Korea, United States, China and, to a less extent, some European countries—have initialized CE programs. Moreover, the author claims that most of these programs are taking place in large industries, while small and medium enterprises will require the incorporation of graduates who have been trained in CE concepts and methods to change the current waste-oriented business model. The article by Geissdoerfer et al. [16] aims at clarifying the similarities and differences of the concepts CE and sustainability, which are often used synonymously. After completing an in-depth bibliographic analysis, they conclude that CE is a condition for achieving sustainability, and that most authors consider just the environmental dimension of CE, without taking into account other sustainability dimensions, especially the social one. A similar criticism can be found in Murray et al. [17], who notice that the CE concept has been traditionally seen as a way to integrate environmental sustainability and production-consumption flows, but without considering the social dimension of sustainability. Hence, these authors propose a more general definition of CE that includes both environmental as well as social dimensions.

Although the benefits of CE are clear from its definition and are appreciated by many organizations, there are several barriers to overcome for achieving a successful adoption of CE. These barriers are identified in Rizos et al. [18], and they include: company culture, no buy-in from leaders, inadequate support from the supply chain, and lack of technological knowledge. Some countries, including the USA, several EU countries, and Japan, have CE action plans. Still, the challenge is to increase the responsibility of consumers, as well as promoting new consumption patterns that are inline with CE principles. There have been studies about some country's approach to the implementation of CE principles. For example, Fonseca et al. [19] perform a survey to investigate the awareness of CE among Portugese companies. In an attempt to provide clues on how to shift from a linear to a circular economy, Bocken et al. [20] propose different strategies that range from product design to business models. The article by Winans et al. [21] also provides a literature review, from which the authors are able to identify practical applications of the CE concept, including: policy instruments (e.g., eco-industrial parks and networks), flows of materials and resources (e.g., plastic, wood, metals, water, etc.), social or technological innovations (e.g., new business models, new bio-friendly materials, etc.). Lieder and Rashid [22] propose a strategy to implement CE actions. Their strategy accounts for the environment, existing resources, and the monetary benefits. Kalmykova et al. [23] introduce two databases; the first one refers to strategies, while the second one includes case studies. As the authors point out, manufacturing, distribution, and sales are not usually included in CE actions, which tend to focus more on consumption and recovery/re-use activities.

Regarding education in CE concepts, Whalen et al. [24] explore the use of serious games to teach CE concepts in engineering degrees and, in particular, the efficient use of critical materials. The authors also highlight the lack of courses including CE principles in higher education, and suggest that these tools offer students a "systems thinking" perspective, thus providing them with a more global view of supply chains in disciplines such as engineering, management, economics, etc. Kirchherr and Piscicelli [25] discuss the relevant role of HE to speed up the shift towards a CE, and provide an example of a course that introduces undergraduate students to the CE concept by employing simulation and a problem-solving approach. Suárez-Eiroa et al. [26] highlight the fundamental role of social education as a way to make the different agents—producers, consumers, policy makers, etc.—more aware of the CE values, thus allowing these agents to acquire a more holistic and long-term perspective on their production and consumption habits. Kopnina [27] describes a learning experience in which students have been asked to analyze two case studies related to CE-oriented enterprises. They are encouraged to investigate both cases and assess their real sustainability level. This author also emphasizes the importance of incorporating CE values into the business academic curriculum, so that society can benefit from a new generation of sustainable-oriented citizens. As pointed out by Mendoza et al. [28], the number of universities incorporating CE concepts in their teaching and research activities is growing fast in recent years. Still, there are not too many experiences in which these concepts have been applied to achieve more sustainable university campuses. Using the University of Manchester as a test field, these authors propose a framework to develop campuses that make a more efficient use of their resources, while guaranteeing a high degree of environmental sustainability. Focusing on the electricity and energy sector, Rokicki et al. [29] discuss the importance of HE in promoting CE values among European students. According to these authors, their analysis of data shows that European countries developing research on CE topics are also the ones with a more developed sustainable energy sector. Finally, Sumter et al. [30] identify the critical knowledge, skills, and attitudes that our current students need to acquire in order to design CE-oriented products and services in the future. Among these, the authors highlight the capacity to evaluate the impact of CE-oriented strategies, the capacity to design recoverable products and services that can be employed multiple times, the skill to involve managers and consumers in CE strategies, and the ability to develop and communicate CE strategies in cooperation with other social agents.

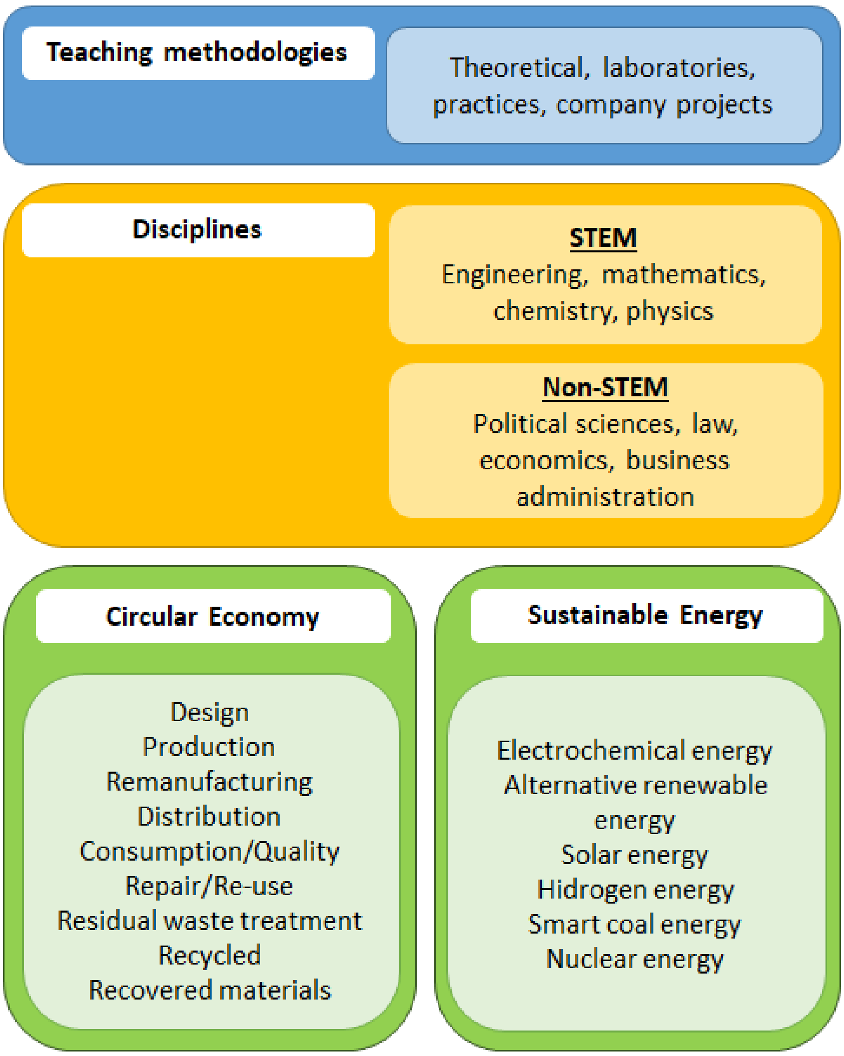

Figure 5. Education program on Circular Economy and Sustainable Energy.

3.2. Sustainability

In the document prepared by the United Nations Commission on Environment and Development, sustainable development is broadly defined as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In the 1997 United Nation's "Agenda for Development" report, it was noted that "Economic development, social development, and environmental protection are interdependent and mutually reinforcing components of sustainable development". These three sustainability pillars (some of which will be discussed later in this section) played a major role in global development. In 2015, "The 2030 Agenda for Sustainable Development" was adapted by the General Assembly of United Nations. The agenda outlined 17 sustainable development goals (SDGs) that could be used by all United Nations member states. These goals can be summarized as follows: SDG 01 (no poverty), SDG 02 (zero hunger), SDG 03 (good health and well-being), SDG 04 (quality education), SDG 05 (gender equality), SDG 06 (clean water and sanitation), SDG 07 (affordable and clean energy), SDG 08 (decent work and economic growth), SDG 09 (industry, innovation, and infrastructure), SDG 10 (Reduced inequalities), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water), SDG 15 (life on land), SDG 16 (peace, justice, and strong institutions), and SDG 17 (partnerships for the goals). Although each of these goals are important by themselves, there has been interest among researchers to study the relationships among them. These studies include Barbier and Burgess [31], Nerini et al. [32], Singh et al. [33], and Fonseca et al. [34]. Zimon et al. [35] studied these goals in the context of sustainable supply chains, and mapped out the goals to sustainable supply chain management practices and metrics. Although some goals have been found to be correlated to each other—and supporting the achievement of each other–, others have shown no significant correlation, which calls for further research in this area.

One of the main keys to mitigating climate change is the change in energy consumption patterns. However, even today, the consumption of sustainable energy is insignificant compared to those obtained from fossil fuel-based sources. Fossil fuels continue to be the predominant source for generating electricity in power plants, in transport (in urban areas, mostly from cars and buses), and for heating homes. Although its reduction is imperative to impact climate change, the costs of mitigating greenhouse gas (GHG) emissions are very high, and many economies, especially those emerging and with high population densities, cannot cope with them. To this end, these mitigation costs must be managed globally and with equity for all [36]. This growing awareness of the environmental impact of community actions has led us to develop more environmentally friendly systems. Some examples are low ecological footprint buildings, photovoltaic and wind, or hydrogen-fueled cars, buses, among others. For example, Chu et al. [37] analyze how advances in solar energy devices, batteries, chemical fuels, and materials are contributing to more efficient and sustainable energy systems. Renewable energy offers immense opportunities in this regard. Another term that is relevant in this context is clean energy, which is any form of energy obtained with harmless methods and free of pollutants for the environment. Thus, sustainable clean energies have the potential to reduce environmental impact (including waste of any nature, especially GHG) and the ability to improve social well-being considering not only current needs but also future ones [38]. In this regard, many cities have started to improve and adapt their infrastructures and services, and to develop new opportunities to achieve sustainability goals. The so-called smart cities aim to change the traditional conception of the city to transform it into a more environmentally sustainable and comfortable complex system, where its inhabitants can work and spend free time, even experiencing a healthy lifestyle [39–41]. However, the condition for this change to take place is the awareness and change of mentality of engineers, managers, and professionals involved in the change [42].

Considering the importance of power generation for climate change, there is an urgency to include energy-related issues in current educational programmes [43,44]. These new programs must be able to provide students with in-depth knowledge regarding the development of new materials and the conversion of systems and devices towards a new consumer paradigm. It is also necessary to reach a certain level of knowledge and recognition, so that they can correctly evaluate the most sustainable alternatives from an integral perspective—i.e., one that includes not only the environmental dimension but also the social one. In a previous work, Bonilla et al. [45] conclude that the two key issues that deserve special consideration in sustainable development initiatives at the university are: (i) efficient use of human resources (in this category are engineers, managers, architects, sociologists, etc); and (ii) the integration of sustainability issues into research topics. Most of the structural changes that must be developed in the universities must come from the hand of the managers' will. Khalili et al. [46] propose a methodology so that university managers can evaluate the need and benefit of specific programs or courses for training in energy sustainability issues. This methodology is capable of evaluating the conditions and limitations that could affect the effectiveness and development of the aforementioned programs. Nowotny et al. [43] detail the efforts being made to establish a reference framework for the inclusion of sustainable energy in university curricula. To achieve this objective, the production of a multi-disciplinary textbook on sustainable energy issues is proposed. According to the aforementioned authors, these new educational approaches will promote the acquisition of the abilities and knowledge required to embrace the new sustainable paradigm.

In a different approach, Pacheco et al. [7] describe the impact of the inclusion of sustainability concepts to the courses which include research projects in conjunction with industry. Authors were able to demonstrate that engineering students were able to learn concepts, abilities and methodologies related to sustainable energy sources despite having been involved in programmes which contain just a few specific topics regarding this issue. Following this adaptive line, Müller et al. [9] analyze the transformative capacity of current university study programs. This flexibility is especially important considering the lack of sustainability concepts, the generation of opportunities and the complexity of managing all changes [47,48]. By implementing their three-phase protocol, the university managers would be able to incorporate sustainability into the existing curricula without major changes (i.e., no changes in course descriptions or module handbooks would be required). Furthermore, the protocol can be also applied during the early years in scientific degrees, where the students have limited knowledge, abilities and resources regarding the topic. By doing so, it is expected to boost critical and reflexive learning from the very beginning.

4. The Role of Simulation-Based Learning

Scholars have researched the effectiveness of simulation-based learning (SBL) in higher education [49,50]. According to some authors, SBL is at least as effective as case study [50] and even more effective than traditional lectures [49]. In general, SBL has been used in higher education for purposes such as training future simulation modelers (mainly in technical degrees such as industrial engineering, operations research, management science, or business analytics), raising awareness for potential simulation users [51], and supporting learning—e.g., by helping students to understand the consequences of various actions [49] or the interaction between components in a system. This section discusses the use of computer simulation to support learning at HE institutions on topics related to the United Nations' sustainable development goals (SDG) and, in particular, on the concepts of CE and sustainable energy.

Challenges in achieving the United Nations' SDGs are multifaceted because of the complex interaction between economic, social, and environmental systems. The same applies to the circular economy and sustainable energy concepts. The systemic complexity inherent in both concepts imposes a non-trivial cognitive challenge to students' learning. Simulation is a tool commonly used to model the complex interactions among components in a system and its dynamics over time. Consequently, simulation can also be used as a tool to help students to learn the dynamic complexity of the underlying system on which the CE and sustainable energy ecosystems operate. It should be noted that this section focuses on simulation that is used in HE teaching as a tool for scenario/what-if analysis, investigating the structure of a system, its behavior analysis, and its experimentation to gain insights. Hence, there is no element of competition between students when they run the simulation as in serious games. These simulation-based games will be discussed in Section 5.

Among the very few studies found dealing with circular economy education at HE level using SBL, Kirchherr and Piscicelli [25] designed a course to introduce CE concepts to the undergraduates of the Faculty of Geosciences at the Utrecht University in Netherlands. One of the features is the use of an eco-industrial park (EIP) simulation, which allows students to explore drivers and barriers that firms in an EIP are facing. Students had to form EIPs with the objective of maximizing employment, annual revenue, and the number of material exchanges to represent the triple bottom line.

SBL has been used in sustainable energy education at HE level. To illustrate its usage, we provide examples from several disciplines: computer science, business and management, chemical engineering, as well as architecture and construction engineering. Thus, in computer science, there is an increasing awareness of the need for green information and communication technology (ICT), which covers sustainable information technologies and systems, as well as sustainable ICT practices. Marques et al. [52] proposed a framework for environmental impact assessment in green ICT. These authors showed the possible applications of simulation to evaluate scenarios in green ICT by evaluating the proposed environmental metrics. The importance of green ICT is shown by the founding of several green ICT related MSc programmes at some universities [53]. Klimova et al. (2016) also described the development of a new MSc that combined advanced ICT with environmental, economic, and social awareness, and where simulation was one of the courses [53]. This fact implicitly acknowledges the potential role of simulation and SBL in the field of green ICT. Actually, as argued throughout this paper, SBL and serious games constitute an important tool for students to learn about sustainability in any field, given the dynamic complexity of the problem.

In business and management, Lieder et al. [54] describe an agent-based simulation that is employed to analyze customers' acceptance of new CE-oriented business models, such as leasing or functional sales. These authors also recognize the need for "social education" in CE values, and discuss how well-designed marketing strategies can contribute to that goal. Making use of the existing literature on CE-related projects, expert criteria, and simulation, Górecki [55] is able to propose a methodology to select CE managers in enterprises. They consider that key aspects for CE managers are vision/imagination and management of material resources, while putting technical skills (e.g., equipment maintenance) at a secondary level. Demestichas and Daskalakis [56] discuss how information technologies—including simulation—can be employed to promote a more CE-oriented society. The authors also emphasize the role of education, funding actions by governments, and multidisciplinary research as facilitators towards achieving CE practices. Bag et al. [57] use simulation to illustrate the potential benefits, in terms of transition towards a CE, of industrial digitization. In particular, these authors focus on analyzing the digitization of the procurement process in South African supply chains. Franco [58] proposes a system dynamics simulation model to measure the transition from a linear to a circular industrial system. This author also points out that CE practices might require higher production and consumption levels in order to make recycling strategies profitable to most businesses.

In chemical engineering, process intensification (PI) is a new toolset that has the potential to deliver the UN's SDGs, and one that is also gaining momentum in industry. PI does not focus on the process only, but also on the impact of the process on the environment, society, and safety. During the workshop conducted by Rivas et al. [59], the participants unanimously stated that a PI course should be made compulsory as energy saving and sustainability are important to the industry. However, introducing the concept and application of the PI principles to an already crowded chemical engineering curriculum will require significant changes. Furthermore, to effectively learn PI principles requires students to work in an environment that is representative to the real world. This is where SBL can be useful. Rivas et al. [59] provided examples, such as the use of process simulation tools, that helped students to understand the impact of different process configurations.

In architecture and construction engineering, buildings are recognized as a major energy consumer. Hence, energy efficient building design has become an important skill for architecture and construction engineering students. This is shown by the many research studies that incorporate sustainability into the curriculum. Many of them use SBL, especially in the use of simulation to estimate the energy consumption. For example, Benner and McArthur [60] conducted a four-year study in which a data-driven design project was incorporated into the curriculum to help students learn about how building design affected its performance (energy consumption and cost). In this project, students used a building information modeling (BIM) approach that estimated the cost and energy of a building based on their design. The feedback from students and result from course evaluations demonstrates that the students benefit from the simulation to refine and develop their designs to improve sustainability. Jin et al. [61] designed a project-based BIM course in which the students need to deliver detailed design of solar-powered residential house that meets some pre-specified objectives, including energy efficiency, budget, and construction scheduling. To achieve these objectives, students need to use simulation to optimize the energy efficiency design and to model construction activities.

As illustrated in the previous examples (and many others not included here), the use of SBL in education and training is widespread. SBL represents a significant departure traditional lecture-based teaching because the students can receive immediate feedback on the measures related to circular economy or sustainable energy from their design choices (e.g., building materials, server configuration, supply chain structure, etc.). This will allow students to explore different designs, which they cannot easily do in real life experiments—this would be too expensive, dangerous, or even unethical in some cases. Hence, they can learn from the mistakes without facing the real life consequences. To the educators, SBL provides electronic log data that can be used to improve the design of the training process or to personalize learning to match the students' progress in achieving specific objectives. The reproducibility of simulation outputs should also allow educators to make fairer comparison among different SBL settings.

5. The Role of Serious Games

Serious games refer to those games whose main goal is other than entertainment, such as knowledge and skills acquisition and behavior change. They make use of a safe environment to experiment and explore different decisions and actions. Despite the similarities with simulation-based learning, the distinguishing factor of serious games are the aspects oriented to players' engagement introduced by competitive and entertainment-related elements. This results in an emotional involvement rather than the impersonal approach that some simulations and other classical learning techniques use. Moreover, they do not need a digital environment: the game In the Loop [24], about circular economy, and the game Energy Safari [62], about energy conservation, are examples of serious board games. Besides, the Energy Transition Game [63] is an example of a role-playing game.

This section revises the principal desired characteristics of serious games to make them useful tools when teaching circular economy and sustainable energy concepts. For a more general perspective of serious games, the reader is referred to Campos et al. [64]. Serious games should pursue high levels of realism to maximize the benefits of such a teaching tool. They allow for the creation of meaningful and realistic narratives that intertwine a multiplicity of actors, market forces, environmental policies, and technological constraints. However, realism should not jeopardize the capacity to understand, follow, and enjoy the game. An interesting aspect of the field of circular economy is the complexity of stakeholders, including companies and customers. Given the role that creativity has in the development of strategies for circular economy, serious games offer an excellent opportunity for experimental innovation in a rich context. Typically, serious games in this field require the consideration of multiple aspects at once in each decision, such as the cause-effect, feedback loops, and interconnection between systems. Players should recognize the non-linearity of their decision-making process. Whalen et al. [24] and Whalen [65] propose the conceptualization and design of new business models within the concept of circular economy, but not other stages such as the implementation, evaluation, and enhancement of the models. From the value chain perspective, serious games should consider covering all stages, from material acquisition to the end of life of the product or service. Bocken et al. [66] highlight the importance of purpose-made tools to address business innovation strategies. The lack of transparency of the tool development and its usage might hinder their usability. They also note the importance of testing these tools with potential users, to involve diverse perspectives, sectors, and stakeholders.

Climate Challenge [67] on renewable energy sources, Energyville [68] on sustainable energy supply, and Encon City on energy conservation [69] are examples of digital serious games addressing the topic of sustainable energy from the perspective of the triple bottom line, that is, including the economy, social, and environmental attributes. Serious games have shown to be an effective tool to reduce the information gap and re-educate incorrect knowledge, which can hinder end-users' transition to more sustainable energies. For instance, through the Energy Games [70] it is demonstrated that proving immediate feedback of the type "right-wrong" answer helps to correct misconceptions, whereas more passive learning approaches can even reinforce the incorrect concepts. In the context of industrial training, Scurati et al. [71] reviews some current work on the use of serious games and simulation for supporting education on sustainable practices. Although the authors notice that their research is in a preliminary stage yet, suggestions such as the incorporation of collaborative activities and negotiation processes in these training courses seem quite promising. Whalen and Kijne [72] discuss the benefits and limitations of using serious games to support education in sustainable innovation. The authors also highlight the difficulties of assessing the results of such learning experiences.

To maximize learners' experience, it is convenient to offer an introduction to the main concepts of circular economy or sustainable energy before starting playing. A reflection process following the game is highly advised to guarantee the messages underpinning the game are efficiently conveyed. For instance, Whalen et al. [24] shows how different initial background results in unequal experiences and interpretations of the game. Moreover, Robin et al. [73], who focus on students from primary schools in France and Switzerland, show the important role of the instructor to facilitate the reflection on sustainability principles. All in all, the main benefit that serious games bring to the learning experience is the holistic consideration of the actors and factors around energy and production and their complex interactions, to eventually help learners to elaborate a multifaceted knowledge. Moreover, the emotional implication of the learning players stimulates critical thinking from an ethical perspective which, in terms of sustainability and circular economy, is an important learning objective that is difficult to implement and practice from a theoretical point of view.

6. An Experience Including Sustainability Criteria in Master Courses

This section describes examples of how simulation-based education can be employed in order to promote CE values among students. In particular, it describes our experience teaching how to deploy sustainable yet efficient transportation systems by means of simheuristic approaches [74], which combine simulation with machine learning and artificial intelligence algorithms to solve optimization problems under uncertainty scenarios. With some adaptations, the course main contents are taught in different on campus and online masters belonging to several European universities, which include: University College Dublin (Ireland), Universitat Oberta de Catalunya [75] and Universiat Autonoma de Barcelona (Spain), as well as Universidade Aberta (Portugal). Here, students have to work in small teams in order to: (i) analyze a complex decision-making challenge, typically one related to the optimization of different sustainability dimensions (monetary, environmental, and social) in last-mile delivery in urban/metropolitan areas; (ii) develop their own methodology, based on previously developed building blocks, and discuss it with their instructor; (iii) once their methodology has been approved, students have to implement it in code and test it against a set of benchmarks; and (iv) a statistical analysis of the numerical results has to be completed, and insights regarding possible trade-offs between alternative strategies—in terms of the different sustainability criteria being considered—have to be drawn from this analysis.

As a first example, Figure 6 displays a toy example where different types of vehicles—diesel and electric ones, including drones—are combined to perform last-mile delivery operations.

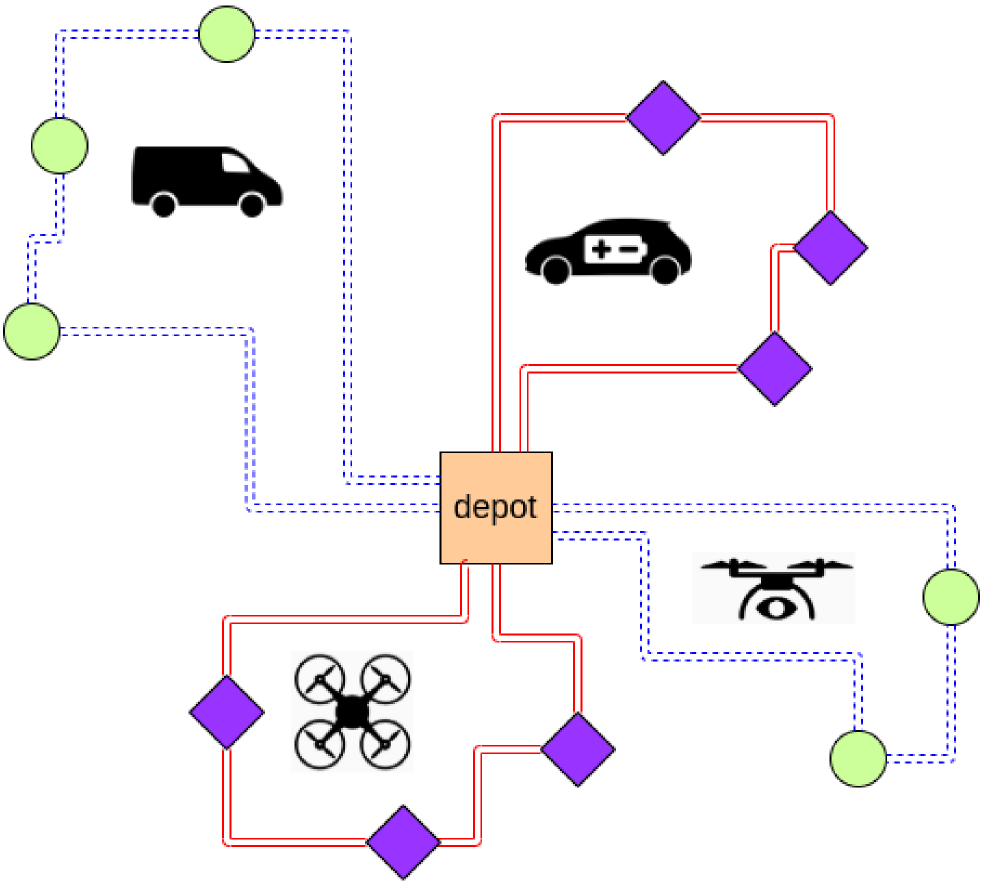

Figure 6. Generating last-mile delivery plans using hybrid fleet configurations with electric and diesel vehicles.

When designing efficient delivery plans, simheuristics allows us to consider stochastic travel and service times [76], which in the case of electric vehicles with limited driving ranges, might force us to consider a safety stock of energy while defining the routes. Of course, real-life problems have a much larger size, which demands advanced simheuristic algorithms such as the ones developed in Gruler et al. [77] for waste collection management, or in Panadero et al. [78] for coordinating a team of surveillance electric drones. Another work where simheuristics are used to design efficient distribution plans under uncertainty scenarios, while considering monetary, environmental, and social criteria, can be found in Reyes-Rubiano et al. [79]. A recent review on simheuristics is provided by Chica et al. [80].

Another example of similar homework activities that promote a more environmentally friendly view of transportation operations are related to the use of horizontal cooperation strategies [81] and intelligent back-hauling [82]. In the former, and following strategies similar to those proposed in Quintero-Araujo et al. [83], students are able to quantify the potential savings in energy and emissions that can be achieved by establishing alliances among carriers. In the latter, Belloso et al. [84] are also able to quantify environmental benefits associated with the effective use of backhauls in long trips, so that trucks do not return empty to their bases. Students use datasets and biased-randomized algorithms, which makes use of simulation to introduce a special randomness into a heuristic procedure [85], to generate a set of alternative solutions to distribution problems [86]. Thus, for instance, Figure 7 shows a simple case in which two carriers, one with origin in depot A (circles) and another with origin in depot B (diamonds), decide to shift from a non-cooperative strategy (upper part of the figure) to a cooperative one (lower part of the figure), where each carrier might service customers of the other. Even in this toy example, one can observe the gains in the distribution plan: less routes (and vehicles) are required to do the job, the total distance traveled is reduced, and one should expect a significant reduction in gas emissions.

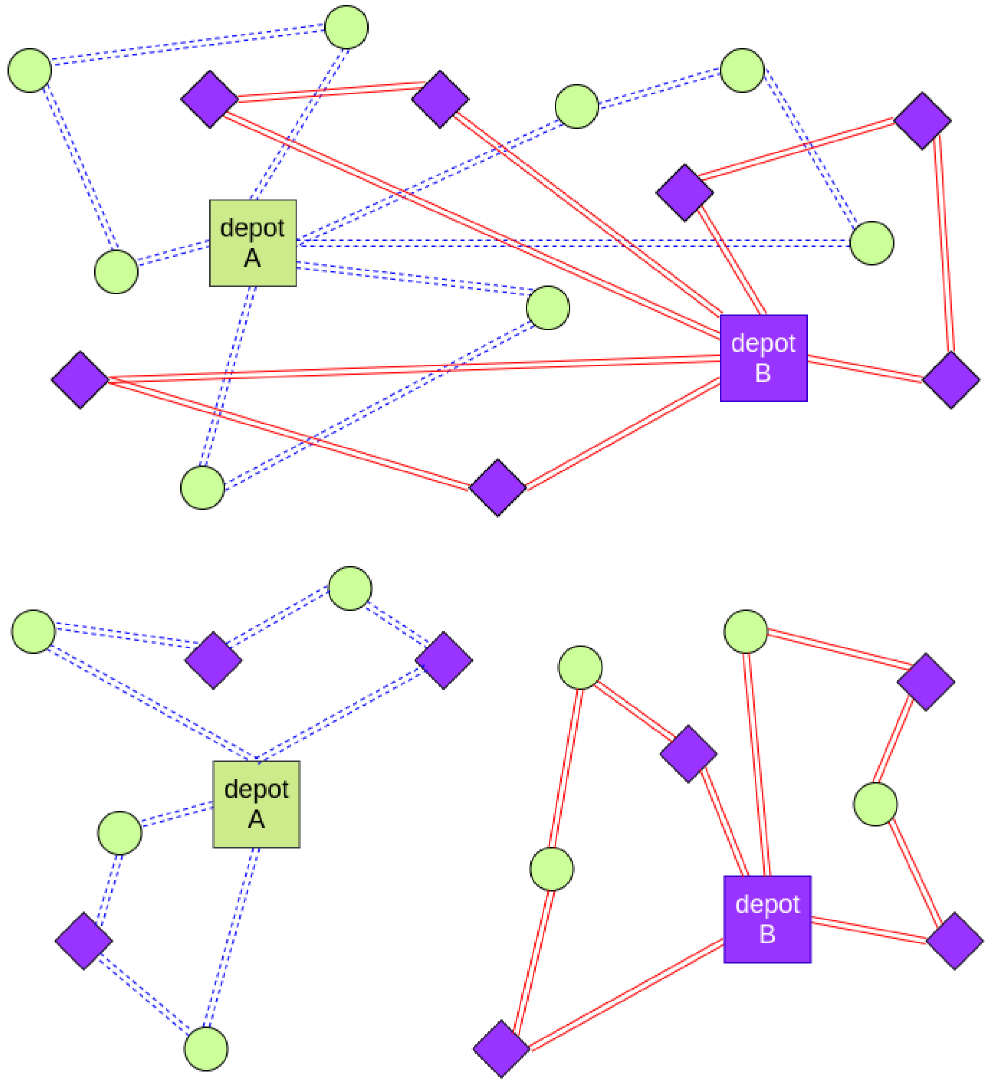

Figure 7. Using horizontal cooperation strategies to reduce energy consumption and gas emissions during transportation activities.

Yet another example—which is analyzed by students of aeronautical management at the Universitat Autonoma de Barcelona—consists of comparing different fuel tankerig strategies for airplanes. Using machine learning in combination with simulation, students have to define a refueling policy for each plane, taking into account the price of fuel at each visited airport, the current normative about lower and upper bounds of fuel loading during the take-off and landing stages, as well as the gas emissions produced by a plane traveling at different speeds and loading levels. Apart from these case studies, master and doctoral students in the aforementioned universities are also invited to read several scientific articles where the use of simulation techniques can be employed—typically in combination with optimization methods—to increase the efficiency of different transportation systems and supply chain networks. For instance, in Fikar et al. [87], the authors describe a novel approach which allows one to reduce traffic congestion and gas emission when providing home healthcare services.

In general, students' feedback on these SBL experiences is quite positive: they value the possibility of learning while designing, analyzing, and solving different scenarios which include not only traditional monetary costs, but also environmental and social factors. They also learn new approaches by reading the scientific articles—although master's students are not required to understand the more advanced technical details. In addition, they have to work in small teams in order to develop their own solutions to the proposed challenges incentives discussion on the relevance of sustainability and CE-related concepts, which need to be taken into account when making decisions on the system characteristics and parameters. Hence, a vast majority of students (near 90% of them) find these SBL learning experiences as "satisfactory" or "highly satisfactory", regardless of the specific university or learning modality.

7. Discussion and Conclusions

HE institutions play an important role in fighting against the climate change through educating citizens in a series of methodologies, skills, and capacities that will led our societies towards a more environmentally friendly and socially sustainable future. To perform this role, HE institutions need to prepare students to recognize the complexity of environmental and social problems related to climate change and to develop critical thinking with sustainability in mind when dealing with problems in their field. Within sustainability, this paper focuses on circular economy (CE) and sustainable energy. On the circular economy, HE institutions can produce graduates who are aware of the CE values, including having a more holistic and long-term perspective when making production or consumption decisions. For engineering, operations research, management science and business analytics students, they need to develop the critical knowledge and skills to design CE-oriented products or services, to evaluate the impact of CE-oriented strategies, and to communicate CE strategies in cooperation with other stakeholders. On sustainable energy, HE institutions need to educate students so that they can correctly evaluate the most sustainable alternatives when making decisions in their future profession.

Teaching CE and sustainable energy is challenging because the systemic complexity inherent in both concepts imposes a non-trivial cognitive challenge to students' learning. This is because the problem is multifaceted and exhibits a dynamics complexity due to the complex interaction between economic, social, and environmental systems. This is where SBL and serious games can help the students better understand the complexity. We have given a number of examples from four different disciplines in Section 4 that demonstrate how SBL can help the students learn about the complexity surrounding problems related to CE and sustainable energy. SBL provides a good pedagogical tool because it makes the best use of the advantage of simulation. Simulation is a tool commonly used to model the complex interactions among components in a system and its dynamics over time. Hence, it can be used to show the impact of certain policy on sustainability measures immediately to the students. It makes the learning more interactive and the students can easily explore different policies and discuss the impact with their peer. The use of serious game adds another dimension to the learning, i.e., emotional involvement, in comparison to the impersonal approach that some SBL and other classical pedagogical tools use. With serious games, students typically play the game with other students so that they can understand different perspectives and how the impact of certain policies can be perceived differently by different people. This makes a serious game a powerful pedagogical tool for learning CE and sustainable energy.

Although there is an increasing awareness of the important role that HE institutions play in the fight against the climate change, there are non-trivial challenges in implementing a syllabus that supports skills and knowledge about CE and sustainable energy within the structure of programmes within the HE institutions. The first challenge consists of developing tools to assist in the decision-making process. It is not obvious how to manage changes in interests and content, course scheduling, syllabus, and subjects. Therefore, it is necessary to provide managers with flexible protocols, models, and methodologies adaptable to their circumstances and limitations, in a format that allows them to decide whether or not to integrate more specialized courses and/or course modules on sustainable development [9,46]. This also includes adding learning indicators adjusted for different program types, expertise, or desirable professional skills. As pointed out by Nunes et al. [10], HE institutions can contribute to a circular economy and sustainable development in several ways. The most trivial way is to integrate those concepts into the curriculum. However, there are other ways to help in the transition to a more suitable society. Among the most important ones, there are: affecting material flows, promoting sustainability outside of the formal curriculum, and acting as catalysts with business [7]. HE institutions are also expected to raise the bar by defining new sustainability standards, boosting related research, and generating new opportunities. For example, the goal could shift from the traditional one of decreasing carbon footprint to a more aggressive goal of achieving 'carbon positivity'. According to Nowotny et al. [43], most of today's initiatives have focused on science, technology, engineering, and mathematics (STEM) studies. However, to bring about changes in society and raise awareness of the need to manage resources in a sustainable way, it is mandatory to join efforts also with non-STEM studies. For example, you will need managers, politicians, and lawyers with initiative, and with a close knowledge of the problem, so new opportunities for improvement can be generated.

Despite the advantage of simulation-based learning and serious games in complementing other pedagogical tools—such as lectures and case studies—to teach topics in circular economy and sustainable energy, the research in this area is still lacking. From our discussion in Sections 4 and 5, we identify the following research challenges:

- Simulation models help create a wide range of practice opportunities and are one of the most effective tools known for analyzing real-word in a simplified way [88,89]. In addition, SBL can be applied from the beginning of students' academic life and allows them to adapt to their difficulties (both for beginners and advanced learners) [90]. It is important to mention that one of the main challenges is that simplifications should maintain value-neutrality, so as not to be biased towards a certain sustainability dimension (e.g., economic, social, or environment) and non-dogmatism (e.g., neither overly enthusiastic nor skeptical). Similarly, the overall teaching material has to be aligned with the same principles, that is, should also be value-neutral and non-dogmatic. Moreover, a static model structure does not reflect possible changes in the real world when simulating medium to long-term plan.
- The literature showed some examples that suggest that educators consider SBL a high impact tool for teaching about the complex, systemic challenges that come with social and environmental sustainability [50,91–93]. However, more empirical evidence is needed to evaluate the effectiveness of SBL. Designing an experiment to compare the effectiveness of SBL for a complex topic such as circular economy and sustainable energy is challenging. First, we have to take into account the adaptability of the tool according to students' personal abilities, capabilities and knowledge, so any disadvantage in achieving the learning objectives can be avoided. Secondly, the difficulty in getting a good sample size may affect the statistical power of the conclusion [50].
- Evidence indicates that there are some serious games that fully contribute to the educational purpose of sustainable development (including the three dimensions, economic, social, and environmental). However, the use of serious games in sustainability is still incipient, and many of the games generated just include two out of the three

aforementioned dimensions (i.e., generally both the social and environmental dimensions serve as a supporting feature while reflecting on the economic aspect) [94,95]. Considering its capacity of adaptation to different teaching methodologies and contents, it is mandatory to encourage a more integrative approach while considering the three dimensions.

- Despite the growing interest and the benefits of the application of serious games as tools in the field of HE, we should emphasize that the development of these games can be complex, expensive, and entail significant challenges (such as the exemplification of reality). One possible direction for future research would be experiential development that helps unravel the keys to achieving holistic learning [69].

All in all, sustainability and circular economy, as two emerging topics, have been long appreciated by industrial organizations and governments. However, in order for more sustainable use of natural resources, knowledge of the role of these concepts by the society is critical. To this end, higher education institutions play a key role in advocating these concepts and providing tools to help the future managers in their decision making process. This paper has reviewed the role of higher education institutions in teaching concepts related to sustainability and circular economy and the challenges associated with teaching those concepts. The role of simulation and the use serious games have been discussed as effective teaching tools to convey those concepts to students.

Although higher education institutions are increasingly aware of their role in building courses that help students experiment with sustainability concepts, it is still challenging to be able to cover all three dimensions of sustainability (social, economic, and environmental) in a single course that can be comprehended by students. Thus, most of the coverage has been limited to environmental concepts. Enhancing those courses with other two dimensions of sustainability is important so that a holistic learning experience can be achieved. Another critical role of higher education institutions in promoting circular economy values is to raise the bar in the standards that governments and other industrial organizations should follow in their acts. As discussed in Nunes et al. [10], one way to achieve this is to build partnerships with industrial organizations.

Simulation is a valuable tool to teach sustainability and circular economy values. However, simulation itself is usually not sufficient to solve problems that arise in real life. Hence, integration of simulation with other tools is important. One approach that was discussed in this paper is the simheuristic approach, which integrates simulation with artificial intelligence algorithms to solve problems that involve uncertainty. Extending this approach to handle dynamic situations and hence developing (and teaching) simheuristics algorithms that allow one to consider real-life systems with uncertainty components is one promising tool to be included in simulation-based education and serious games involving circular economy and energy sustainability concepts.

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