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Features of the Higher Education for the Circular Economy: The Case of Italy

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Abstract: The higher education system plays a critical role in supporting the transition towards a circular economy (CE). It helps create business leaders and policymakers having appropriate skills, competences, and consciousness referring to the CE challenges. Nevertheless, few studies have specifically investigated how the higher education system is addressing the CE, how the current academic offering is integrating the CE principles, and which skills and competences are currently provided. This paper overcomes these limitations by investigating the current offering of the higher education for the CE in Italy. We analyze the academic programs, courses, and modules at different levels of 49 Italian universities and, by means of a detailed classification of the learning outcomes, provide a clear picture of the knowledge, skills, and competences offered by the CE education. We finally discuss implications of our findings concerning the development of CE education and CE jobs.

Keywords: circular economy; education; learning outcomes; circular economy transition; skills and competences

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1. Introduction

Circular economy (CE) is a new industrial paradigm designed to overcome the linear "take, make, disposal" model, which "relies on large quantities of easily accessible resources and energy, and as such is increasingly unfit to the reality in which it operates" [1]. The CE is fully integrated into the broader sustainability paradigm since promising to significantly reduce the environmental and social impact of current production and consumption activities [2] and, simultaneously, provide companies with economic and environmental benefits [3].

A CE is mainly based on three key principles: (1) preserving and enhancing natural capital by controlling stocks of non-renewable resources and balancing renewable resource flows, (2) keeping products and materials in use at most in both biological and technical cycles, and (3) designing out wastes and negative environmental externalities such as pollution [1]. These principles are not completely new; they are inspired by previous concepts such as industrial ecology [4], the "cradle-to-cradle" concept of eco-effectiveness [5], and cleaner production [6]. CE principles can be implemented via slowing (i.e., maintenance, repair, remanufacturing) and closing (i.e., recycling) resource cycles [7].

The transition towards the CE is gaining momentum in the policy plans of many countries. For instance, the European Commission has established a strategic agenda to transform the EU economy into a circular one. It launched the first CE Action Plan in 2015 [8] and the new CE Action Plan in 2020 [9], as one of the main building blocks of the

European Green Deal. Similarly, China has just released the Development Plan for the Circular Economy, integrated into the 14th Five-Year Plan Period (2021–2025).

The transition towards a CE requires the involvement and contribution of a variety of different stakeholders, including both private and public actors. Firms are required to reduce the environmental impacts of their activities by profoundly changing their managerial and organizational practices in using resources (e.g., energy, raw materials, water). CE principles claim for firms to design, manufacture, distribute, and retrieve products differently from the past [10]. Companies are expected to maintain mostly the properties of products and their components, allowing for further efficient re-use or re-manufacturing of resources, as well as for better maintenance [11]. Additionally, a CE requires firms to modify their business models and to adopt proper strategies to implement its principles. In this regard, the Ellen MacArthur Foundation proposes the "Resolve framework", which highlights six CE strategies: REgenerate, Share, Optimize, Loop, Virtualize, and Exchange [12]. A popular way to classify CE strategies is using the "R" frameworks. Kirchherr et al. [2] propose a "4R" framework, which includes reduce, reuse, recycle, and recover. Potting et al. [13] develop a more nuanced framework consisting of ten Rs. They are classified from low to high circularity into recover, recycle, repurpose, remanufacturing, refurbish, repair, reuse, reduce, rethink, and refuse. Kalmykova et al. [14] classify CE strategies in nine groups corresponding to the dimensions of the CE value chain: (1) material sourcing, (2) design, (3) manufacturing, (4) distribution and sales, (5) consumption and use, (6) collection and disposal, (7) recycling and recovery, (8) remanufacturing, and (9) circular input. Recently, Burger et al. [15] distinguish between core CE activities and enabling CE activities. Core CE activities refer to "Prioritization of regenerative resources", "Preservation and extension of what is already made", the "Use of waste as a resource", and "Rethinking of business models". Enabling CE strategies concern "Collaborate to create joint value", "Design for the future", and "Incorporate digital technology".

All organizational functions—including engineering, procurement, marketing and sales, supply chain, design, production, and logistics—are being impacted by the CE transformation and, as a consequence, new and updated skills and competences aligned with the CE principles are required for all these areas. In particular, managers of all business departments should align their skills and competences to the increasing complexity of this new context [16]. Therefore, the transition to a CE is accompanied by profound changes in the labor market. A CE is expected to create new jobs in the energy, production, and services industries [17]. Recently, Burger et al. [15] highlighted that CE jobs—i.e., jobs that contribute directly to the CE—are emerging not only in core CE sectors but also in non-green sectors that support core CE sectors providing them with goods and services. They also noticed that core CE activities require more manual and technological skills than enabling CE activities, which alternatively require more complex cognitive skills.

In this scenario, higher education institutions play a critical role through teaching activities that inform new young generations and reskill professionals according to the new requirements of a CE [18]. In fact, it is widely recognized that education is critical for fostering the change not just in knowledge but also in values and behaviors required to achieve sustainable development [19]. For this reason, education for CE has emerged as a nascent field of study in CE literature.

Despite the great number of studies on education for sustainable development [18], only few studies have specifically investigated how the higher education system is addressing CE teaching and how current academic offerings have been modified by integrating CE principles [20–22].

In particular, studies are fragmented since they have focused on specific academic disciplines [23], without providing a clear and integrated analysis of the degree programs, courses, and modules concerning the CE in general. This limits the establishment of the CE as a discipline by itself. To the best of our knowledge, the Ellen MacArthur Foundation provided the first and only outlook of CE learning offerings in higher education, collecting information on what is being taught where and how, referring to 2018 [24]. The report identifies 138 higher education institutions with CE offerings, of which 51 learning offerings have the words "CE" in the title. These addressed eight main themes: environmental aspects, social aspects, policy levers, digital technologies, design, servitization, circular business models, and system thinking.

Furthermore, the literature on CE education has analyzed the teaching and learning approaches adopted in CE higher education, distinguishing between traditional frontal lessons and innovative active learning approaches ([18,20]), but has devoted very limited attention to identify and characterize the skills and competences provided by the CE programs, courses, and modules. However, this knowledge is critical because it can help clarify the features of the new professional jobs associated with the CE transition [24]. Therefore, the aim of this paper is to address these gaps by answering to the following research questions:

RQ1 Which are the most recent programs, courses, and modules concerning the CE higher education offering in different academic disciplines?

RQ2 Which are the main skills and competences provided by the CE higher education programs, courses, and modules?

We answer these research questions by analyzing the current higher education offering on the CE in Italy. We selected Italy for different reasons. Italy is amongst the European countries with the best value as to the global circularity index. Italy has also promoted many legislative actions to support the adoption of CE principles, such as the Law 221/2015, aimed at fostering green economy and sustainable development, and the Law 216/2020 "Waste Decree", which incorporates the four European directives (851/2018 and 852/2018) containing the CE Package [25]. Furthermore, there are financial incentives for firms to support the development of innovation projects in the CE field (e.g., Transizione 4.0 and R&S Economia circolare decrees).

The paper is organized as follows. We first briefly review the studies on education for CE (Section 2). In Section 3, we present the methodology we followed to answer our research questions. Successively, in Section 4 we describe the main results. The paper ends with discussions (Section 5), limitations, and further research avenues (Section 6).

2. Literature Background

The education system is a key strategic actor to create the right conditions for the socio-technical transition towards a CE because of its fundamental role to develop societies and workforces that are more sensitive to sustainability goals, as well as to help create business leaders and policymakers with appropriate skills, competences, and consciousness referring to the CE challenge [26]. In this regard, education for CE has emerged as a new field of study concerning the role of higher education in supporting the CE transition through teaching, research, and practice [27].

The literature on CE education on teaching has investigated two main issues: (1) the integration of CE principles into traditional disciplines and academic curricula and (2) the teaching and learning approaches best fitting its contents. We briefly review these studies below.

2.1. Integration of CE Principles in Traditional Academic Disciplines

Studies on the integration of CE principles in traditional academic disciplines have mainly focused their attention on design, engineering, and business by highlighting the new contents to provide, the new skills and competences to develop, and by describing specific experiences in diverse contexts.

Leube and Walcher [28] describe how design has been evolving to embrace CE principles [28]. Similarly, Vicente [29] provides an updated state-of-the-art analysis of the topic which identifies past experience, contents addressed, methodologies used, approaches (focused or dispersed) adopted, and teaching staff needs. What emerges is that design for a CE requires the introduction of concepts related to design for longevity (i.e., creating products that, from the producer perspective, can be repaired, upgraded, and remanufactured, and, from the consumer perspective, have a high perceived value) and design for reduced environmental impact and increased efficiency (i.e., implementing activities such as de-materialization, design for disassembly, closed materials loops, and service design) [30]. De los Rios and Charnley [31] highlight that design for sustainability should be followed as guidance for rethinking the design curricula, including both the perspectives of producers (i.e., a deeper knowledge of material composition) and consumers (i.e., a rich understanding of social behavior). Hall and Velez-Colby [32] analyze the development of a CE curriculum into fashion education by proposing a novel approach developed by Amsterdam Fashion Institute's Reality School. Wandl et al. [33] present the results of a project aimed at integrating the concept of CE in urban design and planning courses.

Some studies have addressed the engineering field. Knudby and Larsen [34] focus on manufacturing engineers who are required to develop new competences related to product recovery operations, reverse logistics, integration of reuse and product recovery into the firm's daily operations, and new market development for recovered products. Sanchez-Romaguera et al. [35] and Whalen et al. [7] highlight that engineering students should develop system thinking and collaboration skills to fully comprehend the drivers behind the problems and the possible solution space. However, students should not focus only on technical aspects but become aware of societal [36] and economic [37] aspects as well. Kılkış and Kılkış [38] develop a three-phased approach for integrating the CE principles within a course in energy policy. Venugopal and Kour [39] carry out a two-phase study to examine the development of the CE concept in engineering programs in India.

Recently, some studies have analyzed the introduction of CE principles in business and management curricula. Kopnina [40,41] discusses some teaching experiences related to the CE in the context of undergraduate business education. Sanchez et al. [42] describe the restructuring of an undergraduate construction management course, aimed at integrating it with CE principles.

2.2. Teaching and Learning Approaches for CE Education

Courses and curricula concerning CE in higher education mainly adopt an outcome-based approach, focusing on the learning outcomes the students are expected to possess at the end of the course. For example, Kirchherr and Piscicelli [18] develop a CE course offered to bachelor students at Utrecht University, designed coherently with the teaching principles of interactivity, non-dogmatism, and reciprocity.

However, studies on education for CE highly recommend innovative active learning approaches such as problem-based, project-based, challenge-based, situated, and technology-enhanced learning. They are proven to better fit the CE features of multidisciplinary and critical and system thinking compared to the classical frontal lessons approach. For example, Whalen et al. [20] argue that learning about CE may be facilitated by employing experiential learning through the use of serious games, since the game experience encouraged students to think holistically and reflect critically. They describe the serious game In the Loop (https://intheloopgame.com/(accessed on 20 January 2021)), which introduces players to CE concepts such as systems thinking, remanufacturing, and critical materials. Players take the role of a manufacturer and aim to be the first to reach seven "Progress points" by producing products and making material efficiency strategic decisions. Participants should buy materials and apply alternatives to linear business models by implementing CE strategies (e.g., product as a service, maintenance, repair, reuse, remanufacturing, refurbishing) during the game. Similarly, Schmidt et al. [43] propose a board game to teach CE in engineering education. Kirchherr and Piscicelli [18] describe a drill game played by students at the beginning of the course, where they model the profitability of a drill manufacturer both in the linear and circular (recycling) scenario. They also report the use of an eco-industrial park simulation game, where students grouped in ten organizations had to join two parks to improve economic, environmental, and social performance.

Similarly, Wandl et al. [33] propose a situated learning approach, where students play a role not as a passive audience but as inventors and advocates of best practices. Knudby and Larsen [34] propose a task-based learning approach and adopt the teaching principle employed in innovation, based on cross-disciplinary teams involving students and firms.

A case study approach, where the educator drives the analysis from a real-world problem, is also proposed. For example, Kılkış and Kılkış [38] develop a case study concerning a university-founded dairy facility in Turkey and ask students to develop solutions aimed at improving the energy, water, and food nexus in the local context. Kopnina [44] describes an interactive approach where students develop CE business models for several companies involved in the course.

Rodriguez-Chueca et al. [45] propose a challenge-based learning approach coupled with a flipped classroom. They reported the results of a wider education project in the engineering field carried out at the Polytechnic University of Madrid. The flipped classroom requires students to watch videos on various topics and then answer some questions, providing more classroom time to discuss. Challenge-based learning more actively involves students in solving an industrial problem related to a pulp and paper industry using the life cycle assessment approach and sustainable development indicators. The approach promotes the development of transversal skills such as critical thinking, creativity, leadership, group, and collaborative work.

Some studies recognize that collaboration between academia and industry in jointly developed modules is an effective strategy for teaching and learning CE because it is useful to overcome the classical silo approach to address the complexity and interconnection characterizing CE education. For example, Lanz et al. [46] describe an education module, developed in collaboration between industry and academia, to support the creation of new talents in the field of the manufacturing industry. Williams et al. [47] propose a task-based approach where students are asked to apply circular thinking in a water supply and wastewater treatment company. Students are required to find circular options for water waste reduction, recovery, and reuse that do not interfere with operational effectiveness. This activity, which is designed based on a collaboration between universities and external organizations, allows mutual benefits, such as providing students with employability skills (e.g., team-working, motivation, and leadership).

Co-learning is a further feature characterizing education for CE. Co-learning argues that a group of people can develop skills and achieve knowledge through social interactions and collaboration [48]. Leppänen and Kuula [49] report their experience of a novel course on CE of infrastructure developed in cooperation with industry, where participants are grouped in teams with different backgrounds, including young degree students and further education students. The adult learners provide their practical working experience and holistic approach and the undergraduates, in turn, offer their modern learning and information retrieval skills. Bakırlıoğlu and McMahon [50] developed a design CE program in Ireland based on project-based learning coupled with a co-learning approach which involves designers, industrial partners, and educators, each party with different learning outcomes. From the educational perspective, the co-learning approach proved beneficial because it provided designers with new skills related to design practice and sustainability as well as with the possibility to improve and practice the capabilities acquired. The approach is beneficial for all members. On the one hand, industry partners develop learning outcomes going beyond the specific project-based solutions and develop skills on circular businesses. On the other hand, the educators can better understand the real-life challenges and explore different opportunities for collaborating with industrial partners.

Surprisingly, there is a scarce number of studies investigating the use of technology-enhanced learning in education for CE. This approach is concerned with using digital technologies to support learning and it is particularly indicated in the case of interactivity and system thinking. A notable exception is the work by Türkeli and Schophuizen [51], who recommend the use of open online education (OOE) and a massive open Online course (MOOC) for CE teaching.

3. Methods

We collected data concerning the higher education offerings of the 49 Italian higher education institutions reported in the Europe Teaching Ranking 2019, developed by the Times Higher Education (www.timeshighereducation.com (accessed on 1 December 2020)). Data are referred to from the academic year 2020–2021 and the research was updated on 15 February 2021.

We searched for: (1) bachelors, (2) masters, (3) postgraduate courses, (4) high specialized courses, (5) seasonal schools, and (6) single disciplines. We decided to focus exclusively on those offerings having the words “Circular Economy”, “Circularity” or “Circular” in the title of the course/disciplines. We excluded the offerings including related topics such as sustainability or specific CE strategies (e.g., industrial symbiosis, material efficiency, renewable energy), since our aim is to investigate the establishment of the CE as a new field of study by itself.

To identify the skills and competences provided by the CE education, we analyzed the learning outcomes of the programs, courses, and modules collected. Learning outcomes are specific statements of what learners are expected to understand, know, and/or be able to demonstrate after the learning process. They are required in the design of any course and discipline according to the European Qualifications Framework. Learning outcomes concern knowledge (both theoretical and factual), skills (i.e., the ability to use knowledge to complete tasks), and competences (i.e., the ability to apply knowledge and skills autonomously and with responsibility).

We classified the learning outcomes on the basis of cognitive and content dimensions. The cognitive dimension refers to the Bloom’s taxonomy (1956), which classifies thinking behaviors during the learning process and permits to identify six classes corresponding to increasing cognitive skills (knowledge, comprehension, application, analysis, synthesis, and evaluation). We referred to the new version developed in 2001, where the skills are translating into verbs (remembering, understanding, applying, analyzing, evaluating, creating) (Figure 1). Knowledge refers to *remembering* facts, terms, basic concepts, and answers. Comprehension is related to demonstrating a basic *understanding* of facts and knowledge. Application refers to *applying* the acquired knowledge in different contexts. Analysis corresponds to *examining* in detail and breaking information into parts by identifying causes, motives, and making inferences. Evaluation is related to developing opinions, judgments on something, and making decisions (*evaluating*) Finally, *creating* refers to compiling information together in new ways so as to create something new or propose alternatives.

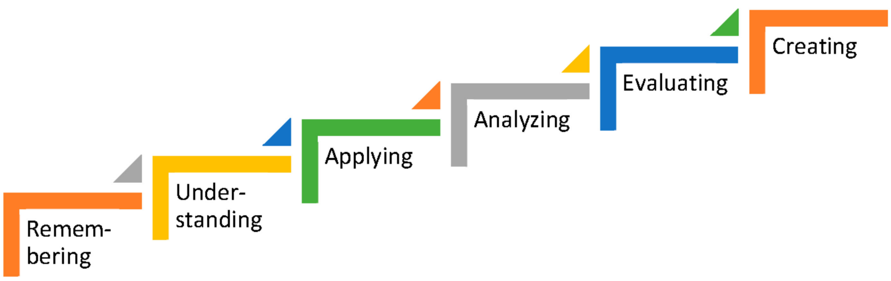

Figure 1. The Bloom’s classification (2001).

As to the content, we referred to the framework proposed by Kirchherr et al. [2], which distinguishes core principles, aims, and enablers of the CE. As to the core principles, we include the ten “R” strategies by referring to the framework proposed by Potting et al. [13], the waste hierarchy, and the systems perspective. As to the aims, we distinguished sustainable development in general, as well as the economic, environmental, and social goals separately, with the attendant measurement indicators. We also included the innovation in this dimension as a further goal of CE applications. Concerning the enablers, we referred to circular business models, customer behavior, and the basics of risk management/change management.

4. Results

Table 1 shows the number of courses and the number of disciplines classified on the basis of the categories defined. Accordingly, there is no bachelor's degree specifically on CE; alternatively, the offering is focused on master's degrees and postgraduate courses. A total of 56 different CE disciplines are offered, out of which 8 are in bachelor's degrees and 48 in master's degrees.

Table 1. Number of CE programs, courses, and modules offered by Italian higher education institutions.

Course	Number
Bachelor program	0
Master program	3
Postgraduate course	4
Highly specialized course	1
Seasonal School	1
Total	9
Module	**Number**
Bachelor program	8
Master program	48
Total	56

Table 2 displays the universities that offer at least one CE program/course or one CE module. It can be noted that 30 out of 49 universities offer at least one CE course or one CE module; in particular, 10 institutions offer at least one CE program/course and 26 institutions offer at least one CE module.

Tables 3 and 4 display the CE programs/courses and the CE modules offered by Italian higher education institutions, respectively. Figure 2 shows that CE modules are offered in 13 out of 20 Italian regions: 33 CE modules are offered in Northern Italy, 16 in Central Italy, and 7 in Southern Italy.

Table 2. Number of CE programs, courses, and modules for each Italian higher education institution.

Higher Education Institution	Number of Programs/Courses	Number of Modules
Marche Polytechnic University	1	2
Polytechnic University of Bari	1	
Polytechnic University of Milano	1	
Polytechnic University of Torino		4
Sant'Anna School of Advanced Studies	3	1
Sapienza University of Rome		1
Tuscia University	1	6
University of Bologna	1	
University of Florence		1
University of Foggia		1
University of Messina		1
University of Milan		1

Table 2. *Cont.*

Higher Education Institution	Number of Programs/Courses	Number of Modules
University of Milan Bicocca	1	
University of Modena e Reggio Emilia		2
University of Naples Federico II	1	1
Parthenope University of Naples		2
University of Padua	1	15
University of Palermo		1
University of Pavia		1
University of Pisa		1
University of Rome III		1
University of Salerno		1
University of Siena		1
University of Turin	1	3
University of Trento		2
University of Trieste		3
University of Udine		1
Ca' Foscari University of Venice		1
University of Verona		1
D'Annunzio University of Chieti-Pescara		2

Table 3. Details on CE programs and courses offered by Italian higher education institutions.

Course		Higher Education Institution
Master program	Sustainability and Circular Economy Management	Marche Polytechnic University
	Circular Economy	Tuscia University
	Sustainable Chemistry and Technology for CE	University of Padua
Postgraduate course	Circular Economy	Polytechnic University of Bari
	Environmental sustainability & circular economy	Polytechnic University of Milan
	Environmental management and control: circular economy and efficient resource management	Sant'Anna School of Advanced Studies
	Bioeconomy in the CE	University of Bologna; University of Naples Federico II; University of Turin; University of Milan Bicocca
Highly Specialized Course	CE for business	Sant'Anna School of Advanced Studies
Seasonal School	Circular Economy and Sustainability Management	Sant'Anna School of Advanced Studies

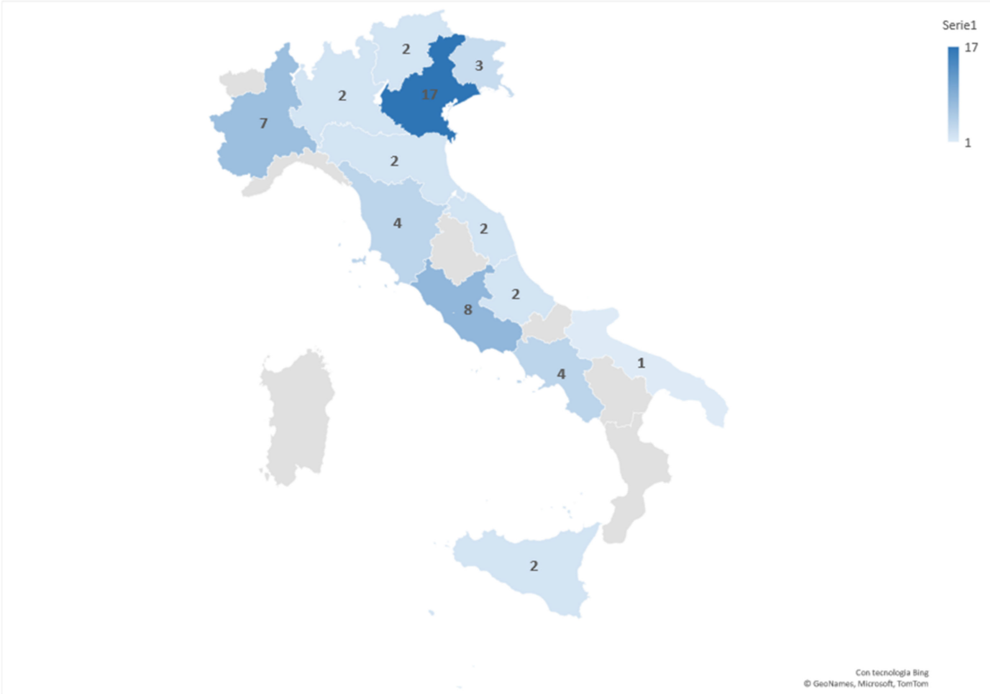

Figure 2. CE modules offered by Italian higher education institutions per region.

Figure 3 shows the distribution of the 56 CE modules according to the scientific areas defined by the Italian National Research Council: 30% belongs to industrial engineering (ING-IND), 26% to economics (SECS-P), 14% to chemical sciences (CHIM), 14% to civil engineering and architecture (ICAR), 8% to agricultural and veterinary sciences (AGR), 5% to statistics (SECS-S), 1% to biological sciences (BIO), 1% to earth sciences (GEO), and 1% to psychology (M-PSI). Considering the specific academic disciplines, the most represented are health and environmental engineering (ICAR-06) with six CE disciplines, management engineering (ING-IND/35) and political economics (SECS-P/02) with four disciplines each, industrial design (ICAR/13), metallurgy (ING-IND/21), chemical plants (ING-IND/25), and applied economics (SECS-P/06) with three disciplines each.

For what concerns the teaching and learning approaches, the description of the single disciplines does not emphasize the adoption of any innovative learning approaches, except for the course at the Polytechnic University of Turin organized as a challenge to promote the entrepreneurial culture/behavior in the CE field. Students are arranged in multidisciplinary teams and are engaged in resolving a real problem coming from partner firms.

In the following, we list the learning outcomes related to CE, identified by collecting the information provided in each program, course, and module, and classified them into the six cognitive classes according to the Bloom's classification.

Table 4. Details on CE modules offered by Italian higher education institutions.

Module	Higher Education Institution
Circular Processes and Chemical-Environmental Plants	Marche Polytechnic University
Elements of circular economy	
Challenge@PoliTo by Students—CE: The right loop	Polytechnic University of Turin
Circular economy and environmental sustainability	

Table 4. *Cont.*

Module	Higher Education Institution
Circular economy for energy storage	
Circular economy design and development	
Circular economy: implications and opportunities for business and policy maker	Sant'Anna School of Advanced Studies
Laboratory of circular economy management	Sapienza University of Rome
Consumer behavior in the circular economy	Tuscia University
Micro and macroeconomics foundations for the circular economy	
Technological innovation for the circular economy	
Econometric models for the circular economy	
Circular design	
Sustainability and circular economy	
Circular economy and sustainable human development	University of Florence
Circular economy for marketing	University of Foggia
Sustainable firm and circular economy	University of Messina
Biomass and waste recycling promoting the CE	University of Milan
Elements of circular economy for agrifood technology	University of Modena and Reggio Emilia
Sustainability and circularity in manufacturing and logistics	
Energy from wastes and circular economy	University of Naples Federico II
Environmental economics and circular economy	Parthenope University of Naples
Sustainable finance and circular economy	
Biorefineries and sustainable energy production and storage for circular economy	University of Padua
Circular and sustainable waste management (two disciplines in two different courses)	
Circular Economics and local development	
Circular economy	
Circularity in biomass productions	
Economics for the circular economy	
Health and environment in circular economy	
Material design and selection for circular economy	
Psychology, policy making, and education to a circular economy	
Sustainability strategies and Innovation management for circular economy	
Sustainable materials and recycling for circular economy	
Thermodynamics and catalysis for circular economy	
Understanding statistics of circular economy	

Table 4. *Cont.*

Module	Higher Education Institution
Water resources management in the circular economy	
Fundamentals of circular economy	University of Palermo
Innovability and circular entrepreneurship	University of Pavia
Sustainability and circular economy	University di Pisa
Circular economy and sustainability management	University of Rome III
Circular economy and environmental policy	University of Salerno
Laboratory of circular economy and waste management	University of Siena
Circular economy management	University of Turin
Circular economy and environmental sustainability	
Innovation for the circular economy	
Circular economy for materials processing	University of Trento
Engineering for circular economy	
Circular economy and recycling	University of Trieste
Sustainable development and circular economy	
Renewable materials and biotransformations for the circular economy	University of Trieste, University of Udine
Dangerous substances in circular processes: risk assessment and management	Ca Foscari University of Venice
Biotechnologies for the circular bioeconomy	University of Verona
Circular models of production and consumption	D'Annunzio University of Chieti-Pescara
Waste recycling and valorization and circular economy	

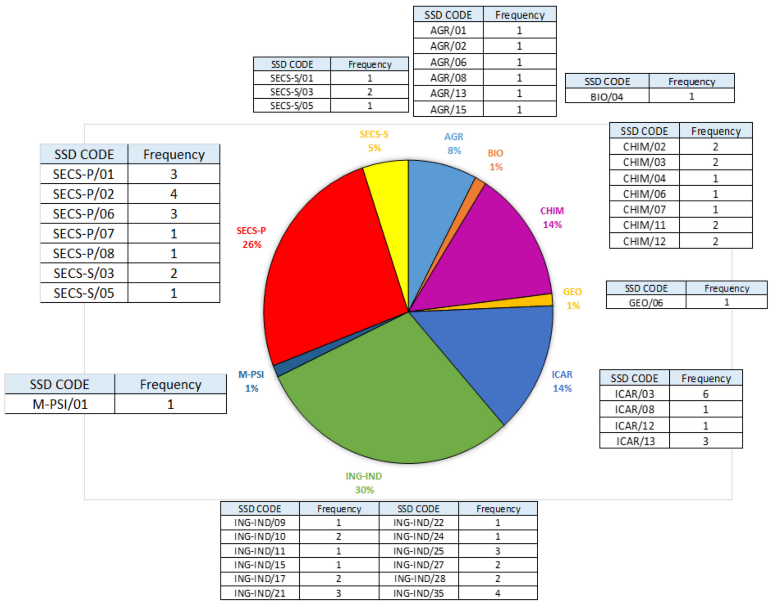

Figure 3. CE modules classified according to the academic disciplines (SSD CODE) defined by the Italian National Research Council. The full description of the SSD codes is reported in Appendix B.

4.1. Remembering

- To know the grand environmental challenges in society.
- To know the pillars of CE: origin, principles, barriers, enablers
- To know the basics of bioeconomy.
- To know the bioplastics and bio-based products.
- To know the normative and legislative frameworks.
- To know the alternative CE business models.
- To know CE value chain activities.
- To know basics of sustainability business and corporate sustainability.
- To know the eco-friendly materials and their properties.
- To know how closing resource cycles.
- To know waste-to-energy technologies and industrial plants.
- To know recycling and waste valorization.
- To know the role of bioenergy.
- To know scientific and technical origins of biomasses.
- To know waste management principles, policies, and legislation.
- To know the plants and equipment for waste storage, collection, transfer, treatment, and disposal.
- To know eco-design principles.
- To know circular supply chain archetypes.
- To know the basics of risk management in a CE.
- To know the possible applications of the biotechnologies.
- To know the criteria of Green Public Procurement.
- To know the principles of Sustainable Entrepreneurship.
- To know how to manage environmental communication as a green marketing tool.
- To know the theoretical approaches of ecological economics.
- To know sustainable resource management.

4.2. Understanding

- To understand the consumer behavior in the CE.
- To understand and describe the main principles of socio-technical transitions.
- To understand the risks involved with the CE transition.
- To understand the design challenges of bio-based products.
- To understand the processing technologies for closing biological and technical cycles.
- To understand the role of materials, resources, and energy in the CE.
- To understand the environmental assessment tools.
- To understand the life cycle assessment framework and analysis.
- To understand the production of biofuels, bioenergy, and biochemical.
- To understand the environmental impact of industrial production in the agriculture sector.
- To understand the potential, the advantages, and the challenges of biorefinery technologies in different contexts.
- To understand the problems related to the waste-resource transformation in the building sector.
- To understand the ecosystemic value of the environmental resources.
- To understand how to manage environmental resources by maximizing the value of ecosystem services.

4.3. Applying

- To apply the concepts of a CE in decision making and business development.
- To apply sustainable issues in new product development.
- To apply digital technologies and sharing platforms for innovating products and processes.
- To manage product and service innovation in the CE.
- To apply environmental certifications.

- To apply environmental assessment tools.
- To apply life cycle assessment.
- To manage critical information for improving material efficiency.
- To apply CE indicators and tools.
- To apply industrial symbiosis mechanisms.
- To apply industry 4.0 technologies to support the adoption of circular business models.

4.4. Analyzing

- To identify CE innovation projects.
- To recognize opportunities and risks in a CE.
- To analyze the value chain of a product, process, and service.
- To compute energy balance, material flow analysis, and recycling indicators.
- To analyze the technological cycles in terms of "R" strategies.

4.5. Evaluating

- To select the most appropriate business models.
- To assess risks concerning greenhouse gas emissions.
- To assess the environmental impact and the economic sustainability of waste recycling and valorization plants.
- To assess the productivity and efficiency of biological and technical resources.
- To evaluate the feasibility of biological products.
- To evaluate the reliability of products.
- To measure and quantify the impacts of a CE model from a normative, economic, and technological point of view.
- To select the materials for engineering applications to reduce the environmental impact.
- To evaluate the technical, economic, and environmental efficiency of circular production and consumption models.

4.6. Creating

- To create a CE action plan in specific contexts.
- To design the indicators to monitor the implementation of the CE action plan.
- To design biological cascade cycles to regenerate biological materials.
- To design technical cascade cycles to regenerate products.
- To design new products and processes with low energy impact.
- To design de-assembling phase of a product.
- To design circular and sustainable supply chains.
- To design sustainable production and logistics processes.
- To develop new CE business models.
- To design new CE business models for the biorefinery sector.
- To design the phases of product refurbishing.

The classification of the learning outcomes based on both the content and cognitive dimensions is shown in Appendix A. The analysis reveals that all the 'R' strategies are covered, with a higher frequency for recover, recycle, reduce, and rethink. As to this dimension, the learning outcomes identified mostly belong to the *remembering* cognitive class.

A high number of learning outcomes also refer to the systems perspective. In such a case, we can observe that the main knowledge concerns the basics, the pillars, the principles, the barriers, and the enablers of the CE, as well as the challenges addressed. A relevant knowledge also regards the CE value chain activities and circular supply chain archetypes. As to this dimension, the learning outcomes identified refer to higher-level cognitive classes, i.e., the *understanding* class (the main principles of socio-technological transitions), the *applying* class (the application of CE in decision making and business development), the *evaluating* class (the ability to measure the impact of CE from multiple points of view), and the *creating* class (the development of a CE action plan).

Multiple learning outcomes cover the aims content dimension. In particular, we find learning outcomes concerning the knowledge about sustainability in terms of business and corporate sustainability, principles of sustainable entrepreneurship, and sustainable resource management. We also find that specific learning outcomes refer to the knowledge and the development of economic and environmental performance, indicators, and tools. Interestingly, we also note that three learning outcomes refer to the application and development of innovations using the CE principles and the adoption of digital technologies.

Finally, we find learning outcomes referring to the enablers of the CE, i.e., the business models, the role of the consumer, and the management of risks. As to the business models, it is fundamental to know the available options and the way they create value, as well as to develop the ability to design circular business models in a given context also by adopting the industry 4.0 technologies. As to the consumer dimension, specific learning outcomes concern the knowledge of the role of green marketing to communicate the CE projects and the consumer behavior for circular products. The analysis of the risks associated with the CE transition is also a relevant learning outcome.

5. Discussion

These papers addressed two main research questions. First, they provided an updated and integrated picture of the current higher education offerings by identifying the degree programs, courses, and modules concerning the CE, with reference to different academic disciplines, while previous studies have focused their attention on specific vertical areas. We found that the CE offering spans different levels, ranging from undergraduate to postgraduate courses. However, it is focused on master's degrees and postgraduate courses, meaning that the discipline is aimed at preparing higher-level professionals. We confirm that education for CE refers to different academic disciplines [18], but mainly concerns engineering, business, management, and chemistry. The absence of subjects in the areas of law, arts, and humanities is noteworthy; however, it represents an important dimension to design and carry out CE projects.

As to the second research question, we identified skills and competences provided by CE higher education, a gap in the current literature, by conducting a detailed analysis of the learning outcomes of the CE programs, courses, and modules. We classified them on the basis of both cognitive and content dimensions. In doing so, our analysis goes beyond the definition of a mere list of courses and modules concerning CE education, as the one provided by the Ellen MacArthur Foundation [24]. We found that the so-called "R" strategies represent the main knowledge, even though some of them (repair, reuse, and refuse) did not receive adequate attention. This is quite surprising since repair and reuse represent two famous strategies of the CE. This could be explained by the procedure we adopted to search the courses/subjects that require the word "circular" in the title.

The most relevant competences regard recovery and recycling. This is not unexpected since the production of energy from waste and the waste valorization, as well as the recycling of plastics and wastes in general, belongs to the most traditional features in CE [18]. It is noteworthy that we found that reduce and rethink have a prominent presence, meaning that these strategies represent the basics of CE knowledge.

We confirmed that the systems perspective is a content dimension in CE education and knowledge and a high number of skills, and competences are provided on this topic.

Our analysis also confirmed that education for CE is highly related to sustainability education [27]. We found different skills and competences related to sustainable development in general and, more specifically, to sustainable goals [18]. However, while the economic and environmental aspects are covered, we found that knowledge concerning the social goals of the CE is missing. The ability to assess and measure the economic and environmental benefits by developing proper CE indicators are further relevant competences that emerged from our analysis.

Finally, relevant knowledge, skills, and competences regard the existence of alternative circular business models and the ability to design models appropriate for a specific context by also exploiting digital technologies. The ability to develop green marketing communication plans, understanding the role of consumer behavior, and knowing and analyzing the risks associated with CE projects were also identified as important skills.

Implications

Our findings provide interesting implications. First, the existence of three master's degrees and five postgraduate courses mentioning the words "Circular Economy" in the title suggest that CE is being established as an independent academic discipline.

Some suggestions to improve education for CE can be also formulated. Since offering in the areas of law, arts, and humanities is totally absent, we believe that specific attention should be devoted to integrating the CE principles also in these fields of study. Furthermore, given that the offering appears to be focused on conventional "R" strategies, we suggest that higher education should devote more attention to new disciplines focused on higher-level "R" strategies such as refuse, repair, and reuse. Furthermore, more consideration should be devoted to specific circular business models such as product as a service and sharing platform. The low attention dedicated to them is a notable limitation of current offerings. Furthermore, education should focus more on the creation of innovation and entrepreneurship skills.

We also suggest increasing the adoption of innovative and active learning approaches based on real projects and problems. This would require designing modules and courses in collaboration with companies and industry associations. In this way, a better and faster alignment between what is actually required by firms and what the higher education system is offering will be also obtained.

Finally, our study contributes to the literature referring to the emerging CE jobs. Based on the analysis of learning outcomes, we confirm that CE jobs are mainly related to waste management, environmental assessment, and product recover, recycle, reducing, and rethinking [15]. However, this is only a part of the CE jobs, corresponding to the most conventional professionals related to the CE. More interestingly, our analysis highlights that a new professional figure is also emerging that can be defined as the "CE manager". Such a role is a high-level manager, with skills and competences distinctive from the classical sustainability manager, in charge of business transformation according to the CE paradigm. They have a background in industrial engineering and/or economics and business, with specific technical and managerial knowledge concerning the design and implementation of the CE strategies, the development of CE action plans, and its control, by monitoring of the actions and by measuring the economic and environmental performance achieved. The CE manager is able to recognize opportunities and risks coming from a CE. They are able to analyze the organizational context and to design appropriate circular business models by leveraging the multidisciplinary knowledge about production technologies, bio-based materials, industrial plants, and industry 4.0 technologies. They interact with all the business departments (procurement, R&D, engineering, design, production, marketing, etc.) to investigate and carry out CE projects concerning the improvement of resource use efficiency, the reduction and valorization of wastes, the extension of product life cycle, the development of sustainable product, and service innovations. The CE manager is thus able to manage complexities and interdependencies by adopting a systemic approach. The CE manager is also able to pursue innovation by adopting the CE principles.

6. Conclusions

In the last years, the higher education system has been involved in the process of modifying its offerings so as to integrate CE concepts in academic curricula and provide new and updated skills and competences required to accomplish the CE transition. A novel field of studies has emerged in the CE literature, which has mainly analyzed the integration of CE principles in specific academic disciplines and the learning and teaching approaches to adopt in the education [52].

This paper contributed to this literature by providing a detailed and integrated analysis of the current higher education for CE, by identifying the programs, courses, and modules offered in different academic disciplines in Italy and by clarifying the knowledge, the skills, and the competences associated with CE, which is missing in the current literature. The findings were useful to provide suggestions to improve CE education, which is of utmost importance to support the CE transition, and to clarify the main features of new CE jobs.

Although our paper has some merits, it suffers some limitations. First, the analysis is focused only on Italy. To have a clear picture of the CE education landscape, the analysis should be extended to include other countries where CE is currently mostly diffused, such as the UK, the Netherlands, China, and the United States of America. Nevertheless, it could be useful to compare the education landscape of these countries to understand how different cultures perceive the CE and to identify differences and similarities in knowledge provided and learning and teaching approaches used.

Second, we only searched for courses/disciplines having the word "circular" in the title. On the one hand, this analysis permitted to have a clear and quick snapshot of the topic and its emergence as an independent and autonomous discipline; however, on the other hand, it could have underestimated the diffusion of CE in academic curricula and, perhaps, it could have favored some scientific areas compared to others. We also neglected to collect data on courses adopting digital technologies such as MOOCs and vocational and long-life learning programs, which could be the objective of future analyses since they are a competitive priority for the European education systems.

Based on the analysis of learning outcomes, we identified knowledge, skills, and competences for CE. However, this analysis represents the offering point of view, and the findings could not correspond to what is mostly required by firms to implement a CE transition (i.e., from the demand point of view).

Finally, we analyzed the role of higher education focusing on teaching activities. Recently, it has been recognized that higher education represents an area of interest for CE as a strategic agent that actively participates in technological and socio-cultural innovation [53]. In this context, the role of higher education is aimed at catalyzing innovation and the upskilling of students as future professionals, citizens, and consumers through exposure to real-life innovation processes not only embedded in the curriculum [54].

Further steps of research will be devoted to looking for specific CE strategies in academic curricula, such as industrial symbiosis, eco-design, resource sharing, and digital technologies. To clearly define knowledge, skills, and competences for CE, further research should be devoted to investigating the education needs from the company perspective. This will contribute to a better professional qualification of CE jobs.

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Appendix A

Table A1. Classification of learning outcomes.

	"R" Strategies												**Aims**						**Enablers**		
	Recover	**Recycle**	**Repurpose**	**Remanufacture**	**Refurbish**	**Repair**	**Reuse**	**Reduce**	**Rethink**	**Refuse**	**Waste Hierarchy**	**Systems Perspective**	**Sustainable Development**	**Economic**	**Environmental**	**Social**	**Indicators**	**Business Model**	**Sustainable Development**	**Economic**	**Risk**
Learning outcomes																					
Remembering																					
To know the grand environmental challenges in society												x									
To know the pillars of circular economy: origin, principles, barriers, enablers												x									
To know the basics of bioeconomy												x									
To know the bioplastics and bio-based products																					
To know the normative and legislative frameworks												x									
To know the alternative circular economy business models																			x		
To know circular economy value chain activities												x									
To know basics of sustainability business and corporate sustainability													x								
To know the eco-friendly materials and their properties																					
To know how closing resource cycles		x	x	x	x	x	x														
To know waste-to-energy technologies and industrial plants	x										x										
To know recycling and waste valorization	x	x									x										
To know the role of bioenergy																					

Table A1. *Cont.*

	"R" Strategies											Aims						Enablers		
	Recover	Recycle	Repurpose	Remanufacture	Refurbish	Repair	Reuse	Reduce	Rethink	Refuse	Waste Hierarchy	Systems Perspective	Sustainable Development	Economic	Environmental	Social	Indicators	Business Model	Sustainable Development	Economic	Risk
To know scientific and technical origin of biomasses																					
To know waste management principles, policies, and legislation												x									
To know the plants and equipment for waste storage, collection, transfer, treatment, and disposal	x																				
To know eco-design principles									x												
To know circular supply chain archetypes												x									
To know the basics of risk management in circular economy																					x
To know the possible applications of the biotechnologies									x												
To know the criteria of Green Public Procurement													x								
To know the principles of Sustainable Entrepreneurship													x								
To know how to manage environmental communication as a green marketing tool																				x	
To know the theoretical approaches of ecological economics												x									
To know sustainable resource management													x								
Understanding																					
To understand the consumer behavior in the circular economy																				x	
To understand and describe the main principles of socio-technical transitions												x									
To understand the risks involved with circular economy transition																					x

Table A1. *Cont.*

	"R" Strategies												**Aims**						**Enablers**		
	Recover	**Recycle**	**Repurpose**	**Remanufacture**	**Refurbish**	**Repair**	**Reuse**	**Reduce**	**Rethink**	**Refuse**	**Waste Hierarchy**	**Systems Perspective**	**Sustainable Development**	**Economic**	**Environmental**	**Social**	**Indicators**	**Business Model**	**Sustainable Development**	**Economic**	**Risk**
To understand the design challenges of bio-based products									x												
To understand the processing technologies for closing biological and technical cycles								X													
To understand the role of materials, resources, and energy in CE												x									
To understand the environmental assessment tools															x						
To understand the life cycle assessment framework and analysis															x						
To understand the production of biofuels, bioenergy, and biochemical																					
To understand the environmental impact of industrial production in the agriculture sector															x						
To understand the potential, the advantages, and the challenges of biorefinery technologies in different contexts	x																				
To understand the problems related to the waste-resource transformation in the building sector	x																				
To understand the ecosystemic value of the environmental resources												x									
To understand how to manage environmental resources by maximizing the value of ecosystem services													x								
Applying																					
To apply the concepts of circular economy in decision making and business development												x									

Table A1. *Cont.*

	"R" Strategies												**Aims**						**Enablers**		
	Recover	**Recycle**	**Repurpose**	**Remanufacture**	**Refurbish**	**Repair**	**Reuse**	**Reduce**	**Rethink**	**Refuse**	**Waste Hierarchy**	**Systems Perspective**	**Sustainable Development**	**Economic**	**Environmental**	**Social**	**Indicators**	**Business Model**	**Sustainable Development**	**Economic**	**Risk**
To apply the lean strategies in logistics operations								X													
To apply sustainable issues in new product development										x			x								
To apply digital technologies and sharing platforms for innovating products and processes									x									x			
To manage product and service innovation in circular economy																					
To apply environmental certifications															x						
To apply environmental assessment tools															x						
To apply life cycle assessment															x						
To manage the product as a service (PPS)									x										x		
To manage critical information for improving material efficiency								X													
To apply circular economy indicators and tools																	x				
To apply industrial symbiosis mechanisms			x																		
To apply industry 4.0 technologies to support the adoption of circular business models																			x		
Analyzing																					
To identify circular economy innovation projects																		x			
To recognize opportunities and risks in circular economy																					x
To analyze the value chain of a product, process, and service												x									
To compute energy balance, material flow analysis, and recycling indicators															x						

Table A1. *Cont.*

	"R" Strategies												**Aims**								**Enablers**		
	Recover	**Recycle**	**Repurpose**	**Remanufacture**	**Refurbish**	**Repair**	**Reuse**	**Reduce**	**Rethink**	**Refuse**	**Waste Hierarchy**	**Systems Perspective**	**Sustainable Development**	**Economic**	**Environmental**	**Social**	**Indicators**	**Business Model**	**Sustainable Development**	**Economic**	**Risk**
To analyze the technological cycles in terms of "R" strategies											x										
Evaluating																					
To select the most appropriate business models																			x		
To assess risks concerning greenhouse gas emissions															x						
To assess the environmental impact and the economic sustainability of waste recycling and valorization plants	x	x												x	x						
To assess the productivity and efficiency of biological and technical resources								X						x							
To evaluate the feasibility of biological products														x							
To evaluate the reliability of products														x							
To measure the impacts of a CE model from a normative, economic, and technological point of view												x									
To select the materials for engineering applications to reduce the environmental impact															x						
To evaluate technical, economic, and environmental efficiency of circular production and consumption models												x									
Creating																					
To create a circular economy action plan in specific contexts												x									
To design the indicators to monitor the implementation of the CE action plan																	x				

Table A1. *Cont.*

	"R" Strategies												Aims						Enablers		
	Recover	**Recycle**	**Repurpose**	**Remanufacture**	**Refurbish**	**Repair**	**Reuse**	**Reduce**	**Rethink**	**Refuse**	**Waste Hierarchy**	**Systems Perspective**	**Sustainable Development**	**Economic**	**Environmental**	**Social**	**Indicators**	**Business Model**	**Sustainable Development**	**Economic**	**Risk**
To design biological cascade cycles to regenerate biological materials		x																			
To design technical cascade cycles to regenerate products					x																
To design new products and processes with low energy impact																		x			
To design de-assembling phase of a product				x																	
To design circular and sustainable supply chains												x									
To design sustainable production and logistics processes																			x		
To develop new circular economy business models																			x		
To design new circular economy business models for the biorefinery sector																			x		
To design the phases of product refurbishing					x																

Appendix B

Table A2. Description of the SSD codes mentioned in the paper.

SSD CODE	Description
AGR/01	Agricultural economics and rural appraisal
AGR/02	Agronomy and field crops
AGR/06	Wood technology and forestry operations
AGR/08	Agricultural hydraulics and watershed protection
AGR/13	Agricultural chemistry
AGR/15	Food science and technology
BIO/04	Plant physiology
CHIM/02	Physical chemistry
CHIM/03	General and inorganic chemistry
CHIM/04	Industrial chemistry
CHIM/06	Organic chemistry
CHIM/07	Principles of chemistry for applied technologies
CHIM/11	Chemistry and biotechnology of fermentation
CHIM/12	Chemistry for the environment and for cultural heritage
GEO/06	Mineralogy
ICAR/03	Sanitary and environmental engineering
ICAR/08	Structural mechanics
ICAR/12	Architectural technology
ICAR/13	Design
ING-IND/09	Energy systems and power generation
ING-IND/10	Thermal engineering and industrial energy systems
ING-IND/11	Building physics and building energy systems
ING-IND/15	Design methods for industrial engineering
ING-IND/17	Industrial mechanical systems engineering
ING-IND/21	Metallurgy
ING-IND/22	Materials science and technology
ING-IND/24	Fundamentals of chemical engineering
ING-IND/25	Chemical plants
ING-IND/27	Chemical technologies
ING-IND/28	Excavation engineering and safety
ING-IND/35	Business and management engineering
M-PSI/01	General psychology
SECS-P/01	Economics
SECS-P/02	Economic policy
SECS-P/03	Public economics
SECS-P/05	Econometrics
SECS-P/06	Applied economics
SECS-P/07	Business administration and accounting studies
SECS-P/08	Management
SECS-S/01	Statistics
SECS-S/03	Economic statistics
SECS-S/05	Social statistics

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