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The heterogeneous skill-base of circular economy employment

Martijn Burger[a,*], Spyridon Stavropoulos[b], Shyaam Ramkumar[c], Joke Dufourmont[c], Frank van Oort[d]

[a] Department of Applied Economics and Erasmus Happiness Economics Research Organization, Erasmus University Rotterdam and Tinbergen Institute, Burgemeester Oudlaan 50, 3062 PA, Rotterdam, The Netherlands
[b] Erasmus Happiness Economics Research Organization, Erasmus University Rotterdam, Rotterdam, The Netherlands
[c] Circle Economy, The Netherlands
[d] Department of Applied Economics, Erasmus University Rotterdam and the Department of Economic Geography, Utrecht University, The Netherlands

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ABSTRACT

This paper examines the opportunities and risks of employment, skills and education that are related to a circular economy (CE) in the United States. Combining occupational skills and education data with a newly introduced definition of CE employment, we compare circular- and non-circular-oriented occupations in terms of skills and abilities. Building on the seminal paper by Consoli et al. (2016) and looking at all occupations within a broad range of CE-related industries, we detect and address heterogeneity in job requirements within the CE. We distinguish core activities within CE employment – focusing on renewable energy, repair, re-use of materials and the sharing economy – from enabling activities, which are focused on management, design, and ICT-applicability of the CE. While core CE-activities generally require more manual and technological skills, enabling activities, in contrast, require more complex cognitive skills. Neither core nor enabling CE sectors, however, are entirely cohesive in terms of skill requirements. Part of the education and skills demand is identifiably driven by 'circularity', particularly with regard to technical skills for the core of the CE. This may require specific education and training programs for future development of the CE.

1. Introduction

As the concept of sustainability becomes more deeply entrenched in contemporary society, there has been increasing attention to the development of the circular economy (CE) in academia, business, and public policy. Economic processes of production, distribution and consumption become more circular when fewer or no unusable final components, products and energy remain at the end of the production and consumption cycle. The large literature on the CE predominantly emphasizes minimizing both waste and the negative impacts of the production process by saving on the materials, labour, energy and capital entrenched in a product (Ellen MacArthur Foundation, 2014; Lacy and Rutqvist, 2015). Studies that have discussed the CE model argue that the growth of the CE will produce several benefits, including a more sustainable environment grounded in the greener use of resources, a harmonious society resulting from improvements in well-being, and the creation of a new business model with – arguably – numerous job opportunities emerging in the near future (Ghisellini et al., 2016; Webster, 2017).

Although those who present the CE as a new business model put new job opportunities at centre stage, relatively little is actually known about employment in the CE. Most studies that have addressed CE employment focus either on estimating how many workers are active in the CE (e. or on calculating the net employment effect of the development of the CE, recognizing that the development of the CE may also crowd out or replace traditional industries. This body of literature has found that CE employment in Western nations typically accounts for between 0.5% and 5% of national employment (Horbach et al., 2015).[1] However, these figures might underestimate the true size of the CE because most studies focus on the 'green' component of the CE only and

* Corresponding author.
E-mail addresses: mburger@ese.eur.nl (M. Burger), stavropoulos@ese.eur.nl (S. Stavropoulos), shyaam@circle-economy.com (S. Ramkumar), joke@circle-economy.com (J. Dufourmont), vanoort@ese.eur.nl (F. van Oort).

[1] However, as noted by Van Oort et al. (2018), there is considerable variation in the methodologies applied and, hence, the comparability of the studies can be questioned.

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neglect the non-green jobs that enable the development of the CE (Van Oort et al., 2018).[2] At the same time, there is mixed evidence regarding the positive net employment effects of the development of the CE, although generally positive employment effects are found with regard to the transition to renewable energy (Meyer and Sommer, 2014), savings of raw materials, and the development of eco-innovations (Horbach et al., 2015).[3]

Despite the growing number of studies assessing the size, growth, and potential of the CE in terms of employment, there is little knowledge of the type of workforce the CE requires. In other words, it is unclear what types of employees will be necessary to accommodate the (potential) future growth of the CE. However, such knowledge is essential to ensure that future labour supply matches labour demand. In this regard, a mismatch between the skills and abilities necessary in the CE and the average skills of workers in the economy at large would signify a need to interest young people in careers in CE-related occupations and to improve and tailor education programs to accommodate future labour demand. Nevertheless, it is important to recognize that the CE is a heterogeneous and composite sector (Van Oort et al., 2018) and that different subsectors of the CE have different knowledge bases in terms of the skills, education and experience they require, given that tasks vary across these sectors.

In this exploratory study, we focus on the knowledge base of the CE and examine the types of skills and education that are required in a CE in the United States. We study the knowledge base of the CE by combining data on occupational skills and education from the Occupational Information Network (O*NET) (see, e.g., Peterson et al., 1999) and sector-occupation data from the Bureau of Labor Statistics (BLS). We not only compare the knowledge base of the CE with the knowledge base of the rest of the economy, but also compare the knowledge bases of different parts of the CE, which are arguably composed of heterogeneous subsets of skilled occupations. The decision to base our comparison on skills and abilities instead of education levels or occupations is grounded in the belief that the latter two do not fully capture the breadth and depth of task complexities within a sector, nor do they capture the associated knowledge base that is needed to adequately perform a job. In addition, solely focusing on occupations would ignore the fact that specific skills and abilities can be used in different occupations and that employees are mobile between occupations (Neffke and Henning, 2013).

Building on the literature on gross employment in the CE (e.g., Elliott and Lindley, 2014; Bowen and Kuralbayeva, 2015; Horbach et al., 2015) as well as on the job analysis literature examining the skill intensity and knowledge bases of sectors and occupations (e.g., Autor et al., 2003; Acemoglu and Autor, 2011; Consoli and Elche-Hortelano, 2010), this article is among the first to examine the job requirements of the CE. To the best of our knowledge, only the work by Vona et al. (2015) and Consoli et al. (2016) addresses the question of whether green jobs differ from non-green jobs in terms of skills and human capital. Vona et al. (2015) found that green skills constitute high-level knowledge and expertise in relation to production, design, and technology. Along similar lines, Consoli et al. (2016) find that, on average, when compared with non-green jobs, green jobs use more high-level cognitive and interpersonal skills and require higher levels of education, work experience and on-the-job training. However, the above-mentioned studies only include some components of the CE, as they focus on green occupations exclusively and do not include non-green CE activities and occupations that are economically and functionally related to green occupations (see Kirchherr et al., 2017).

In this study, we take a sectoral approach by looking at all occupations within broadly defined CE-related industries (including facilitating subsectors), thus providing a more idiosyncratic estimate of the skills needed within the CE. Simultaneously, our broad definition also prompts us to address accompanying heterogeneity within the CE. Hence, our paper addresses the following questions:

1 Are jobs in the CE different from non-CE jobs in terms of required human capital and skills?
2 To what extent are there differences among CE sectors in terms of required human capital and skills?

To answer the above questions, the remainder of this paper is organized as follows. Section 2 introduces our definitions of the circular economy (CE), CE-employment and the relevant knowledge and skill bases. Sections 3 and 4 empirically examine the skills and abilities requirements and the associated educational levels required by CE employment vis-à-vis non-CE employment, as well as by important subgroups within CE employment. Section 5 discusses the results and provides an agenda for future research.

2. Defining circular economy employment

2.1. Circular economy

Over the past years, the CE has been defined in many different ways in the academic and public discourse (Kirchherr et al., 2017). The starting point of our research is the definition of the CE provided by the Ellen MacArthur Foundation, which is regarded as the most employed and cited definition of the CE (Geissdoerfer et al., 2017; Kirchherr et al., 2017):

> "[A CE is] *an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models*" (Ellen MacArthur Foundation, 2012, p. 12).

In other words, a CE makes adequate use of the raw materials that we already have and provides a holistic solution to the growing global commodity problem that arose from the linear 'take-make-waste' economy. In a CE, raw materials are not consumed, but recovered in a system to maintain their highest possible value. Value is thus not lost after the lifetime of a product, but is regained in cycles of reuse, repair, and recycling. Based on this definition provided by theEllen MacArthur Foundation (2012), it is possible to distinguish four core strategies how to move from a linear economy to a circular economy. These four core strategies can be found throughout the whole CE literature and can be easily related to the different elements that are commonly found in the R frameworks (e.g., European Commission, 2008; Sihvonen and Ritola, 2015; Van Buren et al., 2016; Potting et al., 2017; see Table 1) that provide an outline of the 'how-to' of the CE (Kirchherr et al., 2017):

- Preserve and extend what's already made. While resources are in use, maintain, repair and upgrade them to maximize their lifetimes and give them a second life through take-back strategies when applicable. This involves reuse, repair, refurbish, remanufacture, and repurpose of products.
- Prioritise regenerative resources. To ensure that renewable, reusable, non-toxic resources are utilized as materials and energy in an efficient way; this reduces the use of natural resources and materials.
- Use waste as a resource. When one utilizes waste streams as a source of secondary resources and recover waste for reuse and recycling,

[2] Van Oort et al. (2018) also found that CE employment in the Netherlands is increasing at a moderate rate. However, to the knowledge of the authors, theirs is one of the few studies that has examined the dynamics of CE employment.

[3] However, not all aspects of the CE have been researched in this regard, and relatively little is known about the net employment effects of the digitization of the circular economy, recycling, refurbishment and other activities of the circular economy.

Table 1
R Strategies in the Circular Economy Ordered by Degree of Circularity.
Source: Adapted from Potters et al. (2017, p.5) and Kirchherr et al. (2017, p. 224)

R Strategy	Description
0. Refuse	Make product redundant by offering same function with different product
1. Rethink	Make product use more intensive (e.g. sharing)
2. Reduce	Increase efficiency in manufacture by consuming less resources and materials
3. Reuse	Reuse by another consumer of a discarded product that is in good condition
4. Repair	Repair and maintenance of a defective product
5. Refurbish	Restoring an old product and bring it up to date
6. Remanufacture	Using (parts of a) discarded product in a new product with the same function
7. Repurpose	Using (parts of a) discarded product in a new product with a different function
8. Recylce	Processing materials to obtain the same (or lower quality)
9. Recover	Incineration of material with energy recovery

the useful application of materials is more ensured.

- Rethink the business model. One should consider opportunities to create greater value and align incentives through business models that build on the interaction between products and services. One can think here of leasing, rental, and sharing systems. This makes product use more intensive and also involves reuse of products.

In our study, we utilize a measure employment using the definition of the CE of the Ellen MacArthur Foundation (2012), where these four strategies constitute the core of economic activities within the CE. The next subsection further discusses the definition and measurement of employment in the CE.

2.2. Defining employment in the CE

Like the CE itself, CE employment has been defined in many different ways (Horbach et al., 2015; Van Oort et al., 2018). Following the focus on sustainability in public policy, many studies tend to define and label CE jobs as "green jobs" (Horbach et al., 2015) or jobs that contribute substantially to preserving or restoring environmental quality (UNEP, 2008, p. 3). In this vein, the Bureau of Labor Statistics (BLS) defines green jobs as "*jobs in businesses that produce goods and provide services that benefit the environment or conserve natural resources*" (pp:6)'. Likewise, the European Commission (2014, pp.4) suggests that green jobs include "*all jobs that depend on the environment or are created, substituted or redefined in the transition process towards a greener economy*". Based on these definitions, most studies that have tried to assess the size of the CE have focused on estimating the size of sectors that can be labelled as 'green', including the waste and recycling sector as well as renewable energy. At the same time, current studies largely overlook non-'green' CE jobs related to energy and waste-saving measures and the 'sharing' economy which are also included in many definitions of the CE. In addition, focusing solely on 'green' jobs overlooks jobs that enable and support the development of the CE (Horbach et al., 2015; Kirchherr et al., 2017; Van Oort et al., 2018). These activities include jobs in sectors that provide goods and services to the CE core; these jobs are CE-specific and thus promote the growth of the CE. Specifically, one can here think of CE-related jobs in management consultancy, information and communication technology (ICT), and research and design (Van Oort et al., 2018).

A different strand of literature has focused on green *occupations*, defined as occupations that emerge in response to specific needs of the green economy or that are expected to undergo significant changes in terms of task content due to the creation of a green economy (Peters, 2014; Vona et al., 2015; Consoli et al., 2016). Most notably, Vona et al. (2015) developed a measure of green occupations based on a two-step procedure. In the first step, they used data from the Occupational Information Network (O*NET) to determine the ratio between the number of green-specific tasks and non-green specific tasks within a given occupation. Green-specific tasks ranged from conducting sustainability- or environment-related risk assessments and analyzing green product marketing trends to operate balers to compress recyclable materials into bundles or bales. In this fashion, the researchers were able to estimate the greenness of a certain occupation was and to gauge how much time was spent on green activities within that occupation. Here, the researchers found that most green occupations were found among managers and engineers as well as low-skilled production occupations. In the second step, Vona et al. (2015) identified skills that complemented the green skills in occupation by examining the co-occurrence of green skills with other skills. In particular, the researchers found that high-level skills, such as engineering and technical skills, science, sills, and operation management skills are important for green occupations. Based on these findings, Vona et al. (2015) concluded that these high skill requirements are indicative of the contemporary task complexity and use of new technologies (Lin, 2011) within the green economy, and hence, that the development of the green economy sector is still its infancy.

Although the 'green occupation' approach circumvents the sectoral classification problem, 'green occupations' only constitute part of the CE economy and do not provide an adequate and full picture of what skills and knowledge are needed within a CE. Many (general) jobs that directly contribute to the CE – such as administrative and logistics occupations – do not involve any 'green skills' and even do not co-occur with green skills (cf. Vona et al., 2015).

Building on the discussion above, we follow the industry classification of Van Oort et al. (2018) and define circular employment as the number of jobs that contribute directly to the circular economy. More specifically, we argue that the CE contains both *core* circular strategies and *enabling* circular strategies (Van Oort et al., 2018). Core circular strategies include activities surrounding the earlier distinguished 'Prioritization of regenerative resources', the 'Preservation and extension of what is already made', the 'Use of waste as a resource', and the 'Rethinking of business models'. In the related literature that follows a sectoral approach to the CE, these jobs are often referred to as 'green jobs' (Horbach et al., 2015) and include jobs in the recycling and waste management, recycling and maintenance, renewable energy, and rental services sectors. Enabling circular strategies are activities that directly support the core strategies in the circular economy and include:

- Collaborate to create joint value. When work together throughout the supply chain, internally within organizations and with the public sector, this increases transparency and creates joint value. It also brings together different stakeholders in the CE.
- Design for the future. This concerns accounting for the systems perspective during the design process to use the right materials, to design for appropriate lifetimes and to design for extended future use.
- Incorporate digital technology. Here, tracking and optimizing resource use and strengthening connections between supply chain actors is pursued through digital online platforms and technologies that provide insights

Without enabling strategies, circularity in economic processes would not be possible. Furthermore, both types of strategies directly produce CE employment. Examples of CE jobs linked to both core and enabling strategies can be found in Appendix A.

It should be acknowledged that employment in enabling activities only contributes to the CE partially, as firms in such industries serve other (non-circular) markets as well. For example, the jobs of architects are only partially included in the CE, as not all construction projects are designed using energy-saving materials, nor do all activities of the architects support the CE. The part of the enabling industries that is linked to the CE can be estimated by using input-output analysis. Such analyses identify which parts of enabling industries are economically and functionally related to core CE employment (in a similar vein as in Wijkman and Skånberg, 2015; Morgan and Mitchell, 2015; Van Oort et al., 2018). As our aim is not to estimate gross employment in the CE but to identify necessary skills and education levels, this is beyond the scope of this paper.

In this study, we focus on jobs in specific industries that have one of the core and enabling CE activities as their main focus. However, next to core and enabling CE activities, a third category of CE activities that can be distinguished are jobs that are linked to the direct circular jobs category – by means of subcontracting and delivery – but that are not CE-specific. Hence, these indirect jobs support the core and enabling sectors in the CE economy by providing inputs to it, such as logistics and education services. This category of CE jobs is included in the rest of the economy and also beyond the scope of this paper.

3. Examining the knowledge base of the CE

To examine the knowledge base of the CE, we combine data on occupational skills and knowledge from the O*NET, developed under the sponsorship of the US Department of Labor, with sector-occupation data from the American BLS. The O*NET[4] database contains information on occupational requirements and worker attributes and classifies occupations based on the skills and knowledge required, work activities, and typical work settings. In O*NET, data on worker and experience requirements were collected by means of surveys, in which incumbents (employees in a specific occupation), occupational experts, and occupational analysts are asked to rate occupations according to their characteristics. The idea behind the use of a variety of sources is that for the collection of different types of data, different rater groups are preferred. Although employees are best able to provide an overview of their daily tasks and work activities, occupational analysts are generally better than employees at impartially rating the skills necessary to perform a job (Tsacoumis and Van Iddekinge, 2006).

Because our study focuses on identifying the necessary competences of workers (i.e., job requirements) in the CE in the United States, our use of O*NET focuses on worker and experience requirements in terms of education and skills. With regard to education levels, we focus on three measures of education level (see also Consoli et al., 2016) that measure the degree of human capital that ought to be necessary to perform a job. First, the general skill requirements of a job are measured by the formal level of education required, which can range from Elementary or Middle School to Doctorate. However, in order to perform a job, specific skills and knowledge may also be required. So, second, specific job requirements are measured by the number of years of training, and third, learning on the job is measured by the required years of experience.

Apart from generic indices, work-related skills are defined as the ability to perform a task well and are commonly acquired through on-the-job training and/or experience. In the O*NET database, 35 skills are identified (see Appendix B), ranging from active learning and listening to mathematics and programming, which are in turn divided into six groups based on the type of tasks in which they are used:

- Basic Skills: Developed capacities that facilitate learning or the more rapid acquisition of knowledge.
- Complex Problem Solving Skills: Developed capacities used to solve novel, ill-defined problems in complex, real-world settings.
- Resource Management Skills: Developed capacities used to allocate resources efficiently
- Social Skills: Developed capacities used to work with people to achieve goals.
- Systems Skills: Developed capacities used to understand, monitor, and improve socio-technical systems.
- Technical Skills: Developed capacities used to design, set up, operate, and correct malfunctions involving applications of machines or technological systems.

An overview of the taxonomy of the 35 skills can be found in Table 2. The rating of the 35 skills necessary for each occupation was performed by occupational analysts in O*NET. These analysts acquired information on the title and definition of the occupation, level of vocational preparation needed, knowledge background, and importance of work activities and context that require the particular skill. For each occupation, the importance of individual skills was rated on a scale from 1 to 5, ranging from "Not Important" (1) to "Very Important" (5).[5]

In order to calculate the required levels of education and skill for the different CE strategies and the rest of the US economy, the O*NET occupation data need to be linked to employment-by-industry data. The Standard Occupational Classification (SOC) that can be found in the O∗NET database makes it possible to link the O*NET data on occupational characteristics to the 2014 occupation-by-industry matrix of the BLS, which contains information on the occupational structure of each 3- or 4-digit NAICS industry. Because the O*NET classification is more detailed, occupations were aggregated to the 6-digit SOC level, resulting in a database of 822 occupations for 329 NAICS industries.[6] Building on earlier research (Ellen MacArthur Foundation, 2014; Van Oort et al., 2018), we identified 28 NAICS industries that belong to the 7 CE strategy categories (4 core, 3 enabling) introduced in Section 2. An overview of the industries linked to the different CE strategies is provided in Table 3. In our calculations, we use the occupational structure – in terms of the numbers of a specific occupation within an industry – to estimate weighted averages of the education and skill scores across industries and CE strategies.

Overall, employment in the core CE industries in the United States is just over 4% of total employment, which is consistent with previous studies that have examined green sector employment in the United States (which mostly excludes the 'Rethink the Business Model element', see Elliott and Lindley, 2014). Although the enabling CE sectors account for over 5% of total employment, it should be noted that not all jobs in the enabling sectors are linked to the CE. Yet, we assume that the skills and broad education levels necessary in these sectors to support the CE are not structurally different from the skills and broad education levels necessary to be employed in the other activities in these sectors. We acknowledge that this is a strong assumption in that some occupations within the enabling sector are more likely to contribute to the CE than other sectors. However, the available data prevents us to distinguish further between employees that contribute to the CE and other employees in these enabling industries.

4. Analysis

4.1. Occupations in the circular economy

Since occupations are the main source of the variation in skill requirements between the CE and the rest of the economy, we start an examination of which occupations can be regarded as the most 'circular-intensive' occupations, that is the ones for which employment in circular economy industries is the highest over total occupational

[4] This paper uses version 22.0 of O*NET, which appeared online in August 2017 and has information on 965 occupations.

[5] Occupational analysts provide not only importance ratings (1 to 5 scale) but also level ratings (1 to 7), indicating what level of a skill is needed to perform the job. Given the very high rating between the two ratings ($r > .85$ for almost all skills), we only examine importance ratings in this study.

[6] The data were aggregated from 8-digit to 6-digit using a simple unweighted average.

Table 2
Taxonomy of Skills in the O*NET database.

Skill	
Active learning	Basic Skills
Active listening	Basic Skills
Complex problem-solving	Complex problem-solving Skills
Coordination	Social skills
Critical thinking	Basic Skills
Judgment and decision making	Systems Skills
Learning strategies	Basic Skills
Reading comprehension	Basic Skills
Monitoring	Basic Skills
Speaking	Basic Skills
Writing	Basic Skills
Equipment selection	Technical Skills
Management of financial resources	Resource Management Skills
Management of material resources	Resource Management Skills
Management of personnel resources	Resource Management Skills
Mathematics	Basic Skills
Operation monitoring	Technical Skills
Programming	Technical Skills
Quality control analysis	Technical Skills
Science	Basic Skills
Systems analysis	Systems Skills
Systems evaluation	Systems Skills
Technology design	Technical Skills
Time management	Resource Management Skills
Troubleshooting	Technical Skills
Instructing	Social skills
Negotiation	Social skills
Persuasion	Social skills
Service orientation	Social skills
Social perceptiveness	Social skills
Equipment maintenance	Technical Skills
Installation	Technical Skills
Operation and control	Technical Skills
Repairing	Technical Skills

employment. Table 4 provides an overview of the share of 2-digit SOC occupations within the rest of the economy, the CE, and the different elements of the CE. In this table, a dark grey column indicates that this occupation is found disproportionally more in the CE (or element of the CE) than in the rest of economy, while a light grey column indicates that this occupation is found disproportionally less in the CE (or element of the CE) than in the rest of economy. Comparing the CE and the rest of the economy, it is apparent that - on average – occupations in CE sectors require relatively more occupations related to installation, maintenance, and repair and relatively less occupations associated with production and healthcare. Most notably, where in the CE respectively 19% and 13% of the occupations are related to computers and installation, maintenance and repair, these constitute only 2% and 3% of the occupations in the rest of the economy.

Yet, there are considerable differences between the various elements of the CE as we determined it. When we compare the core and enabling elements of the CE, it is apparent that where the core sectors are particularly in need of installation, maintenance, and repair occupations as well as transportation and material moving occupations, the enabling elements require relatively more high-skilled occupation related to – for instance - management, business operations, computers, engineering, architecture, and design.

To further identify 'circular' skills based on occupational profiles, we examined for every 6-digit SOC occupation (1) the share of that occupation's employment that is employed in each CE element relative to the share of that occupation’s employment in the rest of the economy and (2) the share of that occupation’s employment in each CE element relative to the share of that occupation’s employment within its occupational class (2-digit SOC) it falls. Table 5 reports those occupations that are prototypical for the CE elements in that the share of that occupation in the CE element is at least 10 times higher than the share of that occupation in the rest of the economy, and is at least 10 times higher than the share of other occupations in that CE element that fall within the same occupational class. As can be observed from the table,

Table 3
CE Strategies and NAICS sectors.

Industry code (NAICS)	Industry description	Job Type	7 Elements
221300	Water, sewage and other systems	Core	Use Waste as a Resource
562100	Waste collection	Core	Use Waste as a Resource
562200	Waste treatment and disposal	Core	Use Waste as a Resource
562900	Remediation and other waste management services	Core	Use Waste as a Resource
532100	Automotive equipment rental and leasing	Core	Rethink the Business Model
532200	Consumer goods rental	Core	Rethink the Business Model
532300	General rental centres	Core	Rethink the Business Model
532400	Commercial and industrial machinery and equipment rental and leasing	Core	Rethink the Business Model
533000	Lessors of nonfinancial intangible assets (except copyrighted works)	Core	Rethink the Business Model
22110X	Electric power generation: hydroelectric, wind, solar, biomass and geothermal	Core	Prioritize Regenerative Resources
453300	Used merchandise stores	Core	Preserve and Extend What's Already Made
811110	Automotive mechanical and electrical repair and maintenance	Core	Preserve and Extend What's Already Made
811120	Automotive body, paint, interior, and glass repair	Core	Preserve and Extend What's Already Made
811190	Other automotive repair and maintenance	Core	Preserve and Extend What's Already Made
811200	Electronic and precision equipment repair and maintenance	Core	Preserve and Extend What's Already Made
811300	Commercial and industrial machinery and equipment repair and maintenance	Core	Preserve and Extend What's Already Made
811400	Personal and household goods repair and maintenance	Core	Preserve and Extend What's Already Made
517100	Wired telecommunications carriers	Enabling	Incorporate Digital Technology
517200	Wireless telecommunications carriers (except satellite)	Enabling	Incorporate Digital Technology
517400	Satellite telecommunications	Enabling	Incorporate Digital Technology
517900	Other telecommunications	Enabling	Incorporate Digital Technology
518000	Data processing, hosting and related services	Enabling	Incorporate Digital Technology
519000	Other information services	Enabling	Incorporate Digital Technology
541500	Computer systems design and related services	Enabling	Incorporate Digital Technology
541330	Architectural and engineering services	Enabling	Design for the Future
541380	Testing laboratories	Enabling	Design for the Future
541400	Specialized design services	Enabling	Design for the Future
813300	Social advocacy organizations	Enabling	Collaborate to Create Joint Value
813400	Civic and social organizations	Enabling	Collaborate to Create Joint Value
813930	Labor unions and similar labour organizations	Enabling	Collaborate to Create Joint Value

Table 4
Occupational Structure for the CE, CE elements and the Rest of the Economy.

Occupation Group	Rest of the Economy	CE	Preserve and Extend What's already made	Prioritise Regenerative Resources	Rethink Business Model	Use Waste as Resource	Collaborate to Create Joint Value	Design for the Future	Incorporate Digital Technology
Management	6%	7%	*3%*	**9%**	6%	5%	8%	**9%**	**9%**
Business and Financial Operations	5%	7%	*2%*	**12%**	3%	*2%*	**16%**	7%	**9%**
Computer and Mathematical	2%	**19%**	1%	2%	1%	*0%*	1%	**6%**	**43%**
Architecture and Engineering	1%	**8%**	0%	**8%**	0%	2%	0%	**43%**	3%
Life, Physical, and Social Science	1%	1%	0%	**5%**	0%	1%	1%	**6%**	0%
Community and Social Services	1%	0%	0%	0%	0%	0%	**5%**	0%	0%
Legal	1%	0%	0%	1%	0%	0%	0%	0%	0%
Education, Training, and Library	7%	*1%*	*0%*	*0%*	*0%*	*0%*	5%	*0%*	*1%*
Arts, Design, Entertainment, Sports, and Media	1%	2%	0%	0%	2%	0%	**4%**	**6%**	2%
Healthcare Practitioners and Technical	7%	*0%*	*0%*	*1%*	*1%*	*1%*	*0%*	*0%*	*1%*
Healthcare Support	3%	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
Protective Service	3%	*0%*	*0%*	1%	*0%*	*0%*	3%	*0%*	*0%*
Food Preparation and Serving Related	6%	*1%*	*0%*	*0%*	*0%*	*0%*	**12%**	*0%*	*0%*
Building and Grounds Cleaning and Maintenance	3%	1%	*0%*	*0%*	*0%*	1%	3%	*0%*	*0%*
Personal Care and Service	4%	2%	1%	*0%*	*0%*	*0%*	**19%**	*0%*	*0%*
Sales and Related	11%	9%	13%	3%	**34%**	*2%*	*2%*	*2%*	**9%**
Office and Administrative Support	15%	14%	*12%*	*9%*	**16%**	14%	17%	*11%*	16%
Farming, Fishing, and Forestry	1%	0%	0%	0%	0%	0%	0%	0%	0%
Construction and Extraction	5%	*2%*	*1%*	3%	*1%*	**19%**	*0%*	3%	*0%*
Installation, Maintenance, and Repair	3%	**13%**	**44%**	**25%**	**13%**	**6%**	*1%*	*1%*	**8%**
Production	7%	*3%*	7%	**27%**	*1%*	7%	*0%*	*4%*	*0%*
Transportation and Material Moving	7%	7%	**17%**	*1%*	**21%**	**40%**	*1%*	1%	*0%*

Note: Dark grey and bold columns indicate positive deviations from the rest of economy of 3 percentage points or more; Light grey and italics columns indicate negative deviations from the rest of the economy of 3 percentage points or more.

the main CE categories are characterized by distinctive occupational profiles. To exemplify, wind and turbine service technicians are disproportionally found in the 'Prioritise Regenerative Resources' element, recyclable material collectors in the 'Use Waste as a Resource' element, and cellular, and tower equipment installers in the enabling 'Incorporate Digital Technology' element.

Overall, Tables 4 and 5 provide a first indication that the core of the CE (except for the Prioritise Regenerative Resources element) is less skill-intensive than the enabling CE sectors and the rest of the economy in that they are more abundant of vocational occupations and less abundant of managerial and professional occupations. This will be further explored in the next sections, where we will look at formal educational requirements, required work experience, required on-the-job training, and necessary skills to perform a job well.

4.2. Educational requirements in the CE

How does the CE as we determined it differ from the rest of the economy in terms of education requirements? Table 6 compares the educational requirements of the CE and different CE strategies and the rest of the economy, where we look at required education levels, worker experience, and on-the-job training. Table 7 provides the results of weighted least squares regression analyses in which we tested whether the presented differences between the CE, the distinctive CE strategies, and the rest of the economy are statistically significant. In these regressions, industries are weighted according to their level of employment to avoid the possibility that very small industries strongly influence the final parameter estimates. Comparing the CE and the rest of the economy, it can be observed that – on average – jobs in the CE do not require higher formal education levels. Although the effect of the CE dummy on the percentage of jobs requiring a college degree is positive, the effect is statistically insignificant.

Jobs in the CE do, however, require significantly more training on the job and work experience. Compared to the rest of the economy, the CE has a higher percentage of jobs (about 7 percentage points) that require at least 6 years of work experience. Likewise, the CE has 2.5 percentage points more jobs that require at least 2 years of on-the-job training. These differences between the CE and the rest of the economy can be predominantly attributed to differences between occupations. In particular, a large share of the computer and occupations require extensive work experience, while a large share of architectural and engineering, as well as installation, maintenance, and repair occupations, require a lot of on-the-job training (see Appendix C).

In addition, these analyses show that the CE is not a homogeneous

Table 5
Distinctive Occupations within the CE elements.

CE element	Typical Occupations
Prioritise Regenerative Resources	Hoist and winch operators Wind turbine service technicians Power plant operators
Preserve and Extend What's Already Made	Upholsterers Automotive and watercraft service attendants Cleaners of vehicles and equipment Shoe and leather workers and repairers Painters
Use Waste as a Resource	Water and wastewater treatment plant operators Environmental engineering technicians Hazardous materials removal workers Plant and system operators Meter readers, utilities Weighers, measurers, checkers, and samplers Refuse and recyclable material collectors Septic tank servicers and sewer pipe cleaners
Rethink the Business Model	Counter and rental clerks Audio and video equipment technicians Correspondence clerks Mobile heavy equipment mechanics
Collaborate to Create Joint Value	Labor relations specialists Public relations specialists Conservation scientists Sport officials Recreational protective service workers
Design for the Future	Construction and building inspectors Interior designers Architectural and engineering managers
Incorporate Digital Technology	Computer and systems managers Cellular, and tower equipment installers and repairs Telecommunications line installers and repairers Telecommunications equipment installers and repairers Computer hardware engineers

sector. Most core CE industries include occupations that require no college education. Mostly, these are occupations related to installation, maintenance and repair, production, and transportation and moving materials. Only 9% of employment in the category 'Preserve and Extend What's Already Made' requires a college education, while in 'Use Waste as a Resource' and 'Rethink the Business Model,' this figure is approximately 15%. To compare, a considerably higher percentage of employment requires a college education in the three enabling CE sectors (39–63%) and in the rest of the economy (29%). In the enabling CE sector, the high formal education requirements stem from the relatively large number occupations that can be found in the management, business and financial operations, computer, architecture, engineering, and design categories. An exception in the core CE elements is the 'Prioritise Regenerative Resources' category, in which 29% of the jobs require a college education – which is primarily driven by the large number of engineers and scientists that are employed in this CE element.

When examining required work experience across the different sectors, we see that the average required work experience is particularly high for the 'Incorporate Digital Technology' and 'Prioritise Regenerative Resources' categories compared to other CE strategies and the rest of the economy. Whereas 20% of the jobs categorized under 'Incorporate Digital Technology' and 'Design for the Future' and 18% of the jobs categorized under 'Prioritize Regenerative Resources' require more than 6 years of work experience, this figure is only 8% for the rest of the economy and about 7% for the other core parts of the CE. In the 'Prioritize Regenerative Resources' category, the relatively high work experience requirements are largely driven by occupations in management, computing, engineering, and science, which require most work experience of all occupations. In addition, this CE element hosts relatively few jobs in office and administrative support, which require little work experience.

At the same time, education on-the-job is more important in several of the core CE strategies: For the 'Prioritize Regenerative Resources' and 'Preserve and Extend What's Already Made' categories, the required education on the job is substantially higher than for the other CE sectors and the rest of the economy. Compared to the rest of the economy, the percentage of jobs in the 'Prioritize Regenerative Resources' category that require more than 2 years of on-the-job training is almost 11 percentage points higher; for the 'Preserve and Extend What's Already Made,' this figure is about 4 percentage points. Several occupations (engineering and installation, maintenance, and repair) that can be abundantly found in these two core CE elements require a long on the job training before a productive level is reached.

A limitation of the above estimations is that the differences in required formal education, work experience, and education on the job might not driven by 'circularity', but by unobserved industrial characteristics that potentially affect the demand for educated, experienced and trained staff. In order to be more confident whether our results can be attributed to 'circularity', we add 2-digit NAICS dummies to our estimations. In other words, we re-estimated the regression models presented in Table 7, now including 2-digit NAICS-sector dummies. The results of these estimations are shown in Table 8.

From this table it becomes clear that several of the differences in formal education requirements between the CE and the rest of the economy and the different CE elements disappear when adding the NAICS dummies to the regression analyses. This indicates that most of the initially found differences in terms of formal education requirements are not driven by 'circularity'. Although, we find a now a stronger and more positive effect for the 'Collaboration to Create Joint Value' element, it should be noted that the 2-digit industry in which most of the subsectors in this element fall is very heterogeneous in nature.

At the same time, our results regarding differences in work experience and on-the-job training for the core CE elements largely hold when adding industry dummies to the regression analysis, particularly for the 'Preserve and Extend What's Already Made', 'Design for the Future', and 'Incorporating Digital Technology' elements. However, the earlier obtained differences in between the of 'Prioritise Regenerative Resources' and the rest of the economy in terms of required work experience have now become statistically insignificant, signifying that the required amount of work experience and on-the-job training is in the green energy subsectors compared to the fossil and nuclear energy subsectors. Hence, the initially found differences between the 'Prioritise Regenerative Resources' are not driven by circularity, but merely by occupational requirements in the energy sector in general (vis-à-vis the rest of the economy).

4.3. Skill requirements in the CE

We proceed our analysis by analysing the required skill sets. When examining the importance of the separate skills across sectors, it is first of all apparent that there are some (basic) skills that are important (average score higher > 3) in all sectors. These include Time Management, Active Listening, Critical Thinking, Speaking, Reading Comprehension, Monitoring, Judgment, and Decision Making Importance. This finding is not surprising because most industries are characterized by many lower-qualified jobs that are similar in their

Table 6
Profiling the CE: Education and Experience.
Source: authors' calculations based on O*NET; Observations are weighted by industries' employment share

Required Education Levels	Elementary or Middle School (%)	High School (%)	Post-Secondary Education (%)	College+ (%)	
Preserve and Extend What's Already Made	14	40	37	9	
Prioritise Regenerative Resources	2	27	31	41	
Use Waste as a Resource	16	47	22	15	
Rethink the Business Model	20	42	22	16	
Collaborate to Create Joint Value	8	28	25	39	
Design for the Future	1	12	24	63	
Incorporate Digital Technology	2	16	26	56	
Circular Economy	*7*	*24*	*28*	*41*	
Rest of the Economy	*11*	*35*	*25*	*29*	
Required Work Experience	0-1 Months (%)	1-6 Months (%)	6-24 Months (%)	2-6 Years (%)	> 6 Years (%)
Preserve and Extend What's Already Made	22	9	34	29	7
Prioritise Regenerative Resources	13	3	26	40	18
Use Waste as a Resource	21	11	36	24	7
Rethink the Business Model	29	17	24	23	7
Collaborate to Create Joint Value	21	8	33	28	10
Design for the Future	12	5	26	37	20
Incorporate Digital Technology	8	4	28	40	20
Circular Economy	*15*	*7*	*29*	*34*	*15*
Rest of the Economy	*28*	*11*	*30*	*24*	*8*
Education on the Job	0–1 Months (%)	1–6 Months (%)	6–24 Months (%)	> 2 Years (%)	
Preserve and Extend What's Already Made	30	32	26	11	
Prioritise Regenerative Resources	15	34	33	18	
Use Waste as a Resource	29	38	24	9	
Rethink the Business Model	46	32	17	5	
Collaborate to Create Joint Value	40	35	20	5	
Design for the Future	21	35	30	14	
Incorporate Digital Technology	22	40	30	8	
Circular Economy	*27*	*37*	*27*	*9*	
Rest of the Economy	*38*	*35*	*20*	*7*	

Table 7
Profiling the CE: Education and Experience – Weighted Least Squares.

	(1) % College+	(2) % > 6 Years Work Experience	(3) % > 2 Years Education on the Job
Analysis A: Circular Economy			
Circular Economy Sectors	12.60 (7.84)	6.94 (2.65)**	2.55 (1.18)*
Rest of the Economy	●	●	●
Analysis B: Elements of the Circular Economy			
Preserve and Extend What's Already Made	−20.16 (3.15)**	−1.08 (0.87)	4.45 (1.53)**
Prioritise Regenerative Resources	10.96 (2.77)**	8.97 (0.63)**	10.79 (0.60)**
Use Waste as a Resource	−13.82 (3.68)**	−0.98 (1.33)	2.18 (1.90)
Rethink the Business Model	−12.88 (3.57)**	−1.30 (1.21)	−1.38 (1.08)
Collaborate to Create Joint Value	9.50 (8.35)	2.03 (3.71)	−1.65 (1.13)
Design for the Future	33.18 (4.35)**	12.32 (1.93)**	7.41 (1.88)**
Incorporate Digital Technology	28.02 (7.34)**	12.05 (2.87)**	1.49 (0.70)*
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses.
Observations are weighted by industries' employment share. Number of observations in all models is 329 industries. All regressions contain 2-digit NAICS dummies.
** $p < 0.01$.
* $p < 0.05$.

Table 8
Profiling the CE: Education and Experience – Weighted Least Squares – Including 2-digit Industry Dummies.

	(1) % College+	(2) % > 6 Years Work Experience	(3) % > 2 Years Education on the Job
Analysis A: Circular Economy			
Circular Economy Sectors	4.95 (3.24)	5.09 (1.58)**	2.33 (1.41)
Rest of the Economy	●	●	●
Analysis B: Elements of the Circular Economy			
Preserve and Extend What's Already Made	−2.17 (3.92)	3.69 (1.41)**	7.13 (1.86)**
Prioritise Regenerative Resources	4.93 (3.68)	1.55 (1.73)	0.33 (1.38)
Use Waste as a Resource	−4.94 (3.99)	0.55 (1.40)	3.39 (1.46)*
Rethink the Business Model	−4.10 (2.97)	0.18 (1.16)	−1.30 (0.99)
Collaborate to Create Joint Value	27.54 (9.15)**	6.92 (4.03)	0.88 (1.57)
Design for the Future	6.45 (5.00)	5.79 (2.65)*	4.92 (2.38)*
Incorporate Digital Technology	7.12 (5.32)	7.35 (2.71)**	−0.25 (1.43)
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses.
Observations are weighted by industries' employment share. Number of observations in all models is 329 industries. All regressions contain 2-digit NAICS dummies.
** $p < 0.01$.
* $p < 0.05$.

occupational requirements. In our empirical analysis we are, however, mainly interested in differences between sectors. The outcomes of the weighted least squares regression analyses are presented in Tables 9–12. From the regressions, the following conclusions can be drawn.

First, as can be observed from Table 9, the CE requires more complex problem solving skills, resource management skills, system skills, and technical skills compared to the rest of the economy. At the same

Table 9
Profiling the CE: Skills – O*NET Skill Sets – Regression Analysis.

	Basic Skills	Complex Problem Solving Skills	Resource Management Skills
Circular Economy	0.07 (0.07)	0.19 (0.09)*	0.12 (0.04)**
Rest of the Economy	●	●	●
	Social Skills	System Skills	Technical Skills
Circular Economy	−0.05 (0.04)	0.24 (0.10)*	0.28 (0.06)**
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses. Number of observations in all models is 329 industries; Observations are weighted by employment share.
** $p < 0.01$.
* $p < 0.05$.

Table 10
Profiling the CE: Skills – O*NET Skill Sets – Regression Analysis– Including Industry Dummies.

	Basic Skills	Complex Problem Solving Skills	Resource Management Skills
Circular Economy	0.04 (0.04)	0.14 (0.04)**	0.10 (0.04)*
Rest of the Economy	●	●	●
	Social Skills	System Skills	Technical Skills
Circular Economy	−0.03 (0.03)	0.18 (0.05)**	0.36 (0.07)**
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses. Number of observations in all models is 329 industries; Observations are weighted by employment share. All regressions contain 2-digit NAICS dummies.
** $p < 0.01$.
* $p < 0.05$.

time, we find no differences in basic and social skill requirements between the CE and the rest of the economy. These findings hold when controlling for 2-digit NAICS dummies (Table 10). These findings provide support that these observed differences in skills requirements are (at least) partly driven by ‘circularity’.

Second, the core elements of the CE, with the exception of ‘Prioritize Regenerative Resources,’ require lower levels of basic, system, and social skills compared to industries in the rest of the economy (Table 11). However, these differences disappear when adding industry dummies (Table 12), indicating that the observed differences are not likely to be driven by ‘circularity’. In contrast, the ‘Prioritize Regenerative Resources’ core element is very skill-intensive compared to the rest of the economy, but similar to our results regarding education, work experience, the required skills do not differ much from those in

Table 11
Profiling the CE: Skills – O*NET Skill Sets – Regression Analysis.

	Basic Skills	Complex Problem Solving Skills	Resource Management Skills
Preserve and Extend What's Already Made	−0.25 (0.08)**	−0.14 (0.09)	−0.03 (0.05)
Prioritise Regenerative Resources	0.21 (0.03)**	0.36 (0.03)**	0.20 (0.02)**
Use Waste as a Resource	−0.20 (0.07)**	−0.07 (0.05)	−0.02 (0.06)
Rethink the Business Model	−0.15 (0.04)**	−0.14 (0.05)**	0.03 (0.03)
Collaborate to Create Joint Value	0.07 (0.10)	0.09 (0.12)	0.11 (0.08)
Design for the Future	0.29 (0.05)**	0.42 (0.06)**	0.29 (0.04)**
Incorporate Digital Technology	0.20 (0.04)**	0.37 (0.05)**	0.16 (0.03)**
Rest of the Economy	●	●	●
	Social Skills	System Skills	Technical Skills
Preserve and Extend What's Already Made	−0.28 (0.07)**	−0.10 (0.10)	0.53 (0.13)**
Prioritise Regenerative Resources	−0.06 (0.03)*	0.36 (0.03)**	0.52 (0.03)**
Use Waste as a Resource	−0.23 (0.05)**	−0.12 (0.06)*	0.43 (0.03)**
Rethink the Business Model	−0.10 (0.03)**	−0.12 (0.05)*	0.09 (0.09)
Collaborate to Create Joint Value	0.20 (0.06)**	0.11 (0.11)	−0.19 (0.04)**
Design for the Future	−0.02 (0.03)	0.42 (0.07)**	0.25 (0.04)**
Incorporate Digital Technology	0.01 (0.03)	0.47 (0.07)**	0.30 (0.05)**
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses. Number of observations in all models is 329 industries; Observations are weighted by employment share.
** $p < 0.01$.
* $p < 0.05$.

Table 12
Profiling the CE: Skills – O*NET Skill Sets – Weighted Regression Analysis – Including Industry Dummies.

	Basic Skills	Complex Problem Solving Skills	Resource Management Skills
Prioritise Regenerative Resources	0.08 (0.06)	0.14 (0.08)	0.07 (0.05)
Preserve and Extend What's Already Made	−0.02 (0.09)	0.10 (0.09)	0.12 (0.07)
Use Waste as a Resource	−0.04 (0.08)	0.13 (0.08)	0.14 (0.08)
Rethink the Business Model	−0.06 (0.04)	−0.01 (0.05)	−0.04 (0.04)
Collaborate to Create Joint Value	0.31 (0.12)*	0.32 (0.13)**	0.27 (0.10)**
Design for the Future	0.07 (0.05)	0.14 (0.08)	0.16 (0.05)**
Incorporate Digital Technology	0.03 (0.04)	0.16 (0.06)**	0.04 (0.02)
Rest of the Economy	●	●	●
	Social Skills	**System Skills**	**Technical Skills**
Prioritise Regenerative Resources	0.00 (0.02)	0.12 (0.08)	0.15 (0.06)*
Preserve and Extend What's Already Made	−0.19 (0.07)**	0.12 (0.10)	0.68 (0.05)**
Use Waste as a Resource	−0.02 (0.08)	0.07 (0.07)	0.38 (0.07)**
Rethink the Business Model	−0.02 (0.05)	0.00 (0.05)	0.01 (0.10)
Collaborate to Create Joint Value	0.31 (0.07)**	0.33 (0.12)**	−0.06 (0.07)
Design for the Future	−0.05 (0.04)	0.13 (0.09)	0.37 (0.08)**
Incorporate Digital Technology	−0.02 (0.08)	0.26 (0.07)**	0.38 (0.08)**
Rest of the Economy	●	●	●

● Reference category; Robust standard errors in parentheses. Number of observations in all models is 329 industries; Observations are weighted by employment share.
** $p < 0.01$.
* $p < 0.05$.

the non-green energy subsectors.

Third, most elements of the CE, with the exception of the ‘Rethink the Business model’ and ‘Collaborate to Create Joint Value’ elements, require, however, an excess of technical (and manual)[7] skills compared to the rest of the economy. This demand for technical skills is particularly driven by the relatively high technical skill requirements for installation, repair, and maintenance occupations (see Appendix D). This finding holds when adding 2-digit NAICS dummies to our estimations, indicating that at least part of the technical skill requirements ‘circularity’-based.

Fourth, compared to the rest of the economy, the enabling elements of the CE require generally higher skill levels across a larger range of skills, where in part these differences appear to be driven by ‘circularity’. These findings can again be explained by the top drawer occupations found in these elements.

5. Conclusions and discussion

Although the growth of the circular economy (CE) is often associated with expanding job opportunities, evidence regarding its employment effects remains mixed. Rather than focusing on the magnitude of employment related to the CE, this paper has examined the nature and requirements of this (future) labour market. In order for economies to successfully transition to the work to be carried out in the CE, labour supply should match labour demand. The present paper has therefore attempted to answer the question of what types of employees are needed to accommodate the CE now and in the future, how CE-requirements in education, experience and skills differ from those in non-CE sectors and occupations, and what heterogeneity there is within various CE-subsectors that focus on different elements in the broader defined CE-process.

From our analysis, it appears that the CE constitutes, much like the rest of the economy, a very heterogeneous labour market in terms of both education levels and skills. Within the CE, we have differentiated between employment in core and enabling CE sectors. On average, core sectors require lower education levels, while enabling sectors require higher levels than the rest of the economy. Jobs in core CE sectors are also generally less skill-intensive than those in enabling CE sectors, except for a notably higher need for technical skills. Overall, jobs in enabling CE sectors display a higher demand across the whole range of skills. In this regard, the broadening of the definition of the CE we introduced in our analyses implies the broadening of skills in selective and sorting-sensitive skills enabling ICT and design, indeed leading to above-average skill-upgrading

The CE thus entails a diverse and heterogeneous labour market with disparate education levels and skill requirements across CE strategies and sectors, not particularly different from the rest of the economy. Although ‘green jobs’ may require some specific skills (see also Vona et al., 2015; Consoli et al., 2016), this does not hold for the CE in general. There is no single particular level of education or single specific set of skills that the education system and training programs should provide in order to foster a circular labour market. Of prime importance for a CE is a high degree of diversity in labour supply, both in terms of education and skills.

However, part of the high education and skills demand is identifiably driven by ‘circularity’, particularly with regard to technical skills for the core of the CE. This may require specific education and training programs for future development of the CE. Since the core of the CE especially requires work experience and on-the-job training, one can especially think here of fostering public-private partnerships that link vocational education to business as well as apprenticeships and physical learning environments. One can think here of physical learning environments, in which professionals learn to convert traditional energy installations into sustainable installations for the ‘Prioritise Regenerative Resources’ element of the CE and of sector-initiated training courses on the circular economy for the ‘Rethink the Business Model’ element.

Education and skill-enhancing individual programs are mainly in

[7] The 35 individual skills can be subdivided into six task clusters based on the degree of routine and cognition they require (Autor et al., 2003; Consoli and Elche-Hortelano, 2010): cognitive routine, cognitive non-routine, cognitive interpersonal, and manual skills. This additional classification is useful to distinguish between skills needed for tasks that involve clear protocols and skills needed for tasks that require creativity. When we re-estimate our model using this alternative skill-set, we find that the core of the CE particularly requires manual skills. These results are available upon request.

the hands of (higher) education institutes and of industries themselves, offering on-the-job training, experience gathering and career opportunities. There may be a larger role for government attention to the CE though, as individual companies and education institutes may not feel responsible for the system linkages of functional skill-relatedness, regional resilience, and crossover opportunities within the larger definition of the CE that we defined in our research. Introducing a broader definition of the CE (from strictly defined "green jobs" to including the larger enabling sectors) meant that more heterogeneity but also linkages between industries become important to distinguish when discussing the CE. If the heterogeneity within CE employment in its categories is not addressed in larger labour market contexts, regional or national development strategies, and structural change discussions, the skill-base of CE-employment and sustainability goals that encompass firm and institution level competences may remain unaddressed. Within the debate on such embedding of the circular economy in society and policies (ranging from subsidizing grassroots initiatives to legislation change and international value chain integration), it has been argued that without a good understanding of the precise meaning and detailed skill-requirements of the CE system, the concept can arguably collapse (Kirchherr et al., 2017).

Although the extent of labour markets are important for individual workers and their skills, the precise scale of governance still remains ambiguous though. The CE does not assume that city or country borders will close material loops – a hypothesis often posted in CE-debates (Ellen MacArthur Foundation, 2017). Innovation and economic development dynamics mean that localized economies can specialize, and certain regions will be more, or less specialized in specific CE activities according to positions in value chains (Van Oort et al., 2018) and specialisations built up in the past (Neffke et al., 2011). As such, in regard to regional and global economies, it is essential to understand the geographical spread of economic activity according to the different CE strategies in order to adequately develop education and training programs. Further research on this topic is required.

In addition, the current research did not take in that many parts of the CE are susceptible to computerization and that computerization can lead to a skill-downgrading in most of the CE sectors, both in terms of required education levels and in terms of required skill sets (see Frey and Osborne, 2017). Although this would, on the one hand, facilitate the implementation of the CE, it would also imply that highly educated people who, in the coming years, will help to build up the CE might need to find employment elsewhere in the economy later on. Future research should therefore take in the degree to which current skills and related occupations are at risk of becoming obsolete due to computerization, taking also in possible new, not-yet-existent skills that may become important in the future.

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Appendix A. Illustrations of CE jobs types

Source: Van Oort et al. (2018)

Directly Circular Jobs	
Core jobs	**Enabling jobs**
Prioritise regenerative resources - Solar Panel Installer The solar panel installer works within the energy sector to promote the use of solar as a renewable energy source. The job contributes to the CE by 'prioritizing regenerative resources', the first strategy of the CE.	Collaborate to create joint value - Director of a Trade Association The director of a trade association manages a membership organization composed of multiple companies within a specific industry. The director can support the CE by encouraging greater collaboration, knowledge sharing, and networking between companies. As such, the director can employ the 'collaborate to create joint value' strategy in order to contribute to the CE.
Preserve and extend what's already made - Appliance Technician The appliance technician contributes to the CE by extending the lifetime of products. By embodying one of the strategies of the CE, 'to preserve and extend what's already made', all repair and maintenance jobs are considered circular.	Design for the future - Architect An architect is responsible for designing buildings and, by extension, for the materials used during a building's construction, its energy efficiency during the use phase and the potential for material recovery when it is demolished. An architect can thus contribute to the CE by 'designing for the future'.
Use waste as a resource - Recycling Operative The recycling operative's job consists of sorting through recyclable waste and separating materials to be recovered. This sorting and separating constitutes an essential element in the recycling process, which involves the 'use waste as a resource' strategy and thus presents itself as a circular job. Day-to-day activities of the recycling operative include physical labour and machine handling such as forklift driving.	Incorporate digital technology - Data Analyst The data analyst makes sense of large amounts of information by means varying from simple data aggregation to complex data mining. The data analyst's occupation involves the 'incorporate digital technology' strategy and thus allows for smart systems and technology integration in the CE. This job often requires tertiary education in relatively new fields of data science and computer engineering.
Rethink the business model - Leasing Process Manager The leasing process manager is responsible for the coordination of the external service partners distributed across market segments. By contributing to the workings of a product as a service model, the leasing process manager contributes to the CE through the 'rethinking the business model' strategy	

Indirectly Circular Jobs
The courier The courier's job does not directly contribute to the CE; however, they can play a role in enabling reverse logistics schemes for circular businesses. When the number of circular activities increases, the demand for logistics services will grow. At the same time, the more circular the operation of these logistic services, by, for example, using renewable resources, the more circular their jobs will be.
The teacher The teacher does not directly contribute to the CE; however, they can play a role in educating the future work force about the CE. CE education ranges from vocational training to tertiary education and therefore pertains to both core and enabling circular jobs. During a transition to the CE, education and training needs will evolve, and so will the jobs catering to those needs.

Appendix B. Description of Skills (Obtained from O*NET, Tsacoumis and Willison, 2010)

Basic Skills: Developed capacities that facilitate learning or the more rapid acquisition of knowledge

- Active Learning — Understanding the implications of new information for both current and future problem-solving and decision-making.
- Active Listening — Giving full attention to what other people are saying, taking time to understand the points being made, asking questions as appropriate, and not interrupting at inappropriate times.
- Critical Thinking — Using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems.
- Learning Strategies — Selecting and using training/instructional methods and procedures appropriate for the situation when learning or teaching new things.
- Mathematics — Using mathematics to solve problems.
- Monitoring — Monitoring/Assessing performance of yourself, other individuals, or organizations to make improvements or take corrective action.
- Reading Comprehension — Understanding written sentences and paragraphs in work related documents.
- Science — Using scientific rules and methods to solve problems.
- Speaking — Talking to others to convey information effectively.
- Writing — Communicating effectively in writing as appropriate for the needs of the audience.

Complex Problem Solving Skills — Developed capacities used to solve novel, ill-defined problems in complex, real-world settings

- Complex Problem Solving — Identifying complex problems and reviewing related information to develop and evaluate options and implement solutions.

Resource Management Skills — Developed capacities used to allocate resources efficiently

- Management of Financial Resources — Determining how money will be spent to get the work done, and accounting for these expenditures.
- Management of Material Resources — Obtaining and seeing to the appropriate use of equipment, facilities, and materials needed to do certain work.
- Management of Personnel Resources — Motivating, developing, and directing people as they work, identifying the best people for the job.
- Time Management — Managing one's own time and the time of others.

Social Skills — Developed capacities used to work with people to achieve goals

- Coordination — Adjusting actions in relation to others' actions.
- Instructing — Teaching others how to do something.
- Negotiation — Bringing others together and trying to reconcile differences.
- Persuasion — Persuading others to change their minds or behavior.
- Service Orientation — Actively looking for ways to help people.
- Social Perceptiveness — Being aware of others' reactions and understanding why they react as they do.

Systems Skills — Developed capacities used to understand, monitor, and improve sociotechnical systems

- Judgment and Decision Making — Considering the relative costs and benefits of potential actions to choose the most appropriate one.
- Systems Analysis — Determining how a system should work and how changes in conditions, operations, and the environment will affect outcomes.
- Systems Evaluation — Identifying measures or indicators of system performance and the actions needed to improve or correct performance, relative to the goals of the system.

Technical Skills — Developed capacities used to design, set-up, operate, and correct malfunctions involving application of machines or technological systems

- Equipment Maintenance — Performing routine maintenance on equipment and determining when and what kind of maintenance is needed.

- Equipment Selection — Determining the kind of tools and equipment needed to do a job.
- Installation — Installing equipment, machines, wiring, or programs to meet specifications.
- Operations Analysis — Analyzing needs and product requirements to create a design.
- Operation and Control — Controlling operations of equipment or systems.
- Operation Monitoring — Watching gauges, dials, or other indicators to make sure a machine is working properly.
- Programming — Writing computer programs for various purposes.
- Quality Control Analysis — Conducting tests and inspections of products, services, or processes to evaluate quality or performance.
- Repairing — Repairing machines or systems using the needed tools.
- Technology Design — Generating or adapting equipment and technology to serve user needs.
- Troubleshooting — Determining causes of operating errors and deciding what to do about it.

Appendix C. Average levels of required formal education, work experience, and on the job training by occupational class

SOC-2 code	Description	% College+	% > 6 Years Work Experience	% > 2 Years Education on the Job
11	Management	65.6	9.9	36.0
13	Business and Financial Operations	75.3	12.3	13.4
15	Computer and Mathematical	69.7	8.5	23.2
17	Architecture and Engineering	74.6	18.5	23.0
19	Life, Physical, and Social Science	85.5	8.7	15.6
21	Community and Social Services	86.4	8.9	5.9
23	Legal	79.6	24.0	20.5
25	Education, Training, and Library	77.9	5.8	5.1
27	Arts, Design, Entertainment, Sports, and Media	56.8	10.4	13.0
29	Healthcare Practitioners and Technical	49.1	4.6	7.7
31	Healthcare Support	2.5	2.0	0.2
33	Protective Service	5.5	5.3	2.7
35	Food Preparation and Serving Related	4.8	1.4	2.0
37	Building and Grounds Cleaning and Maintenance	10.2	1.9	1.5
39	Personal Care and Service	13.4	3.0	0.6
41	Sales and Related	21.0	3.2	5.5
43	Office and Administrative Support	17.2	4.2	3.1
45	Farming, Fishing, and Forestry	4.7	2.3	1.8
47	Construction and Extraction	3.5	27.1	9.7
49	Installation, Maintenance, and Repair	2.3	17.0	8.1
51	Production	3.5	5.5	8.2
53	Transportation and Material Moving	3.0	3.3	3.1

Appendix D. Average levels of required skills by occupational class

SOC-2 code	Description	Basic Skills	Complex Problem Solving Skills	Resource Management Skills	Social Skills	System Skills	Technical Skills
11	Management	3.43	3.58	3.28	3.48	3.36	1.73
13	Business and Financial Operations	3.33	3.44	2.59	3.06	3.21	1.45
15	Computer and Mathematical	3.20	3.53	2.43	2.85	3.35	2.31
17	Architecture and Engineering	3.42	3.66	2.66	2.92	3.29	2.21
19	Life. Physical. and Social Science	3.59	3.63	2.51	3.01	3.27	1.89
21	Community and Social Services	3.47	3.46	2.37	3.56	3.18	1.40
23	Legal	3.41	3.73	2.49	3.28	3.18	1.33
25	Education. Training. and Library	3.42	3.30	2.31	3.35	2.97	1.40
27	Arts. Design. Entertainment. Sports. and Media	3.09	3.25	2.53	3.12	2.91	1.61
29	Healthcare Practitioners and Technical	3.49	3.42	2.51	3.33	3.09	1.80
31	Healthcare Support	2.95	2.83	2.17	3.05	2.39	1.49
33	Protective Service	3.04	3.01	2.13	3.11	2.67	1.66
35	Food Preparation and Serving Related	2.59	2.55	2.14	2.83	2.30	1.44
37	Building and Grounds Cleaning and Maintenance	2.33	2.32	1.98	2.47	2.08	1.74
39	Personal Care and Service	2.85	2.89	2.15	3.08	2.54	1.47
41	Sales and Related	2.90	2.78	2.29	3.20	2.53	1.38
43	Office and Administrative Support	2.91	2.79	2.29	2.90	2.47	1.35

45	Farming. Fishing. and Forestry	2.52	2.65	2.04	2.50	2.09	2.05
47	Construction and Extraction	2.70	2.90	2.30	2.64	2.47	2.29
49	Installation. Maintenance. and Repair	2.82	3.10	2.37	2.60	2.79	2.89
51	Production	2.64	2.75	2.18	2.47	2.42	2.20
53	Transportation and Material Moving	2.52	2.62	2.11	2.48	2.26	2.04

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