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Advancing circular economy performance indicators and their application in Spanish companies

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ABSTRACT

Current research on the circular economy (CE) reveals that, while the concept and its application have been extensively explored as shown in several case studies, the definition of tools and criteria measuring "circularity" of products, companies or regions are not well-defined. Therefore, indicators for measuring the different levels of a CE (micro, meso, and macro) should be a high priority for stakeholders (governments, companies, NGOs, civil society, etc.) in order to track progress on CE initiatives. However, the increasing interest on CE has caused a still open debate on the conceptualization of CE which hampers the creation of indicators based on a common conceptual framework. As a result, the absence of standard indicators to track progress on circularity is leading to contradiction and misunderstanding, which represents a challenge to the implementation of CE strategies. Thus, this study tries to address this gap by advancing a set of indicators adapted from existing indicators that guarantees simplicity and effectiveness, closely based on indicators proposed by government bodies. This research carried out an exploratory study to formulate the indicators requirements based on literature, refined through experts' opinion and then they were tested in Spanish companies located in the Basque Country region through an empirical work to assess this theory. A mix of research methods (e.g. semi-structured interviews and surveys) were used to seek applicability of CE indicators for organisations. The study showed that the proposed indicators currently used for assessing the CE at the macro level were applicable at the micro level based on companies' responses. This fact demonstrated that the indicators serve the purpose of being applicable to companies regardless of the type of economic activity they were in. Also, it shows that indicators used to monitor progress on CE at the macro level can be translated to the micro level. Consequently, it is recommended that the set of CE indicators focused on the methodology proposed in this study should be used across different industrial sectors in order to observe performance in companies to facilitate the transition to a CE model.

1. Introduction

The application of the circular economy (CE) paradigm fundamentally aims to prevent the depletion of resources and to close energy and material loops all the way through its different levels: enterprises and consumers within a micro level (Ormazabal et al., 2018), economic agents integrated in symbiosis as part of a meso level (Vanessa Prieto-Sandoval et al., 2018) and city, regions and governments embedded at the macro level (Winans et al., 2017). In practice, these three levels are the approaches considered by researchers and practitioners for the implementation of CE (V. Prieto-Sandoval et al., 2018; Yuan et al., 2006).

Some authors have agreed on what constitutes each level. According to Ormazabal et al. (2016) the micro level refers to companies that are centred on their own improvement in processes and business development. Companies at this level are found to have a positive relationship between their environmental management maturity level and their willingness to implement CE due to related cost-efficiency benefits and the positive impact it creates on their reputation among costumers.

Whereas, Geng et al. (2012a, b) describes the meso level as a level in which companies belong to an industrial symbiosis that will benefit not only the regional economy but also the natural environment. In this scenario, companies advance to a level whereby resources are exchanged through industrial networks (Ormazabal

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et al., 2018). While the focus at the macro level is on the development of a broad strategy meant to promote sustainable development of society in cities, regions and countries through environmental policies and institutional influence (Yuan et al., 2006).

Although, the CE concept and its benefits in several studies have been extensively explored, research on CE shows that indicators intended to capture the CE contributions at different levels are still not clear (Figge et al., 2018). Circularity indicators for measuring CE performance are essential to track progress in order to encourage different stakeholders at different levels to drive implementation towards this new model (Cayzer et al., 2017). The usefulness of indicators to assess circularity performance is critical to improve and measure feasibility of CE models (Smol et al., 2017). However, measurement of performance on CE practices is not common to comprehend, especially in companies (Sassanelli et al., 2019). Thus, some authors have discussed the need to develop and apply suitable indicators to measure CE strategies (Corona et al., 2019).

Studies carried out on indicators for measuring the application of multiple CE strategies is still in its infancy, particularly at the micro level, which some authors have claimed the necessity to create CE indicators at this level (Elia et al., 2017; Linder et al., 2017; Lonca et al., 2018). Saidani et al. (2019b) estimated that only 36% of the indicators reviewed come from the micro level, and especially from Europe (85%). It is in Europe where the focus on indicators keeps gaining attention (Huysveld et al., 2019; Pauliuk, 2018), mainly at the macro level where common guidance in applying and measuring CE strategies and indicators is particularly well developed (European Commission, 2018).

In recent years there has been reported in the literature indices and frameworks on CE indicators at different levels that has turned into multiple metrics for measuring circularity (Pauliuk et al., 2017). Elia et al. (2017) have found indicators to be one-dimensional which indicates progress based on only one aspect of CE. Most of the circularity indicators have been questioned for not representing the systemic nature of the CE. This, in turn showcases a hurdle to comprehensively assess information regarding CE strategies (Saidani et al., 2019a; Smol et al., 2017; Tecchio et al., 2017). As a result, the tools and criteria that have been defined for measuring the level of circularity for products, companies or regions do not share a common set of standards (Haas et al., 2015).

The absence of standard indicators to track progress on circularity is leading to contradiction and misunderstanding, which represents a challenge to the implementation of CE strategies (Corona et al., 2019; Iacovidou et al., 2017). Consequently, a standardized indicator framework for driving and improving actions within countries, enterprises and products has not been widely adopted (De Wit et al., 2018).

This might be explained due to an still open debate on the conceptualization of CE which hampers the creation of indicators based on a concept agreed upon (Llorente-González and Vence, 2019; Reike et al., 2018). This distortion in the CE conceptualization has been reflected on the indicators being created for measuring CE strategies (Geng et al., 2013; Parchomenko et al., 2019; Pauliuk, 2018). Moraga et al. (2019) concluded that CE indicators developed until now do not measure every of the CE strategies set in place.

Moreover, the approaches used to measure circularity commonly overlook the characteristics of circular loops and the multi-dimensional characteristics of sustainability performance (Saidani et al., 2017). In contrast, indicators on CE that embrace multi-dimensional characteristics might support manufacturing firms to perceive the benefits towards a sustainability model involving social and environmental practices (Awan et al., 2017).

Due to the lack of coherence among concepts and their indicators, for instance companies cannot be helped during their transition from a linear to a circular business model, as there is currently no uniform methodology to assess and benchmark their progress (European Commission, 2015; Smol et al., 2017). Authors such as Iacovidou et al. (2017) state that in order to address this gap to ease the transformation to a CE model, existing indicators that guarantees simplicity and effectiveness can be used to facilitate this process.

The selection of proper indicators to measure circularity in decision-making processes, particularly at the micro level must continue, and it should be done by taking into consideration the work done by others, especially in Europe if apparent agreement has been attained (e.g. European Commission's monitoring framework). In this context, it is constructive to highlight the conceptual framework of CE by the European Commission (EC) under its CE strategy and the follow-up set of indicators released to measure CE under its monitoring framework (European Commission, 2018, 2015).

The EC assembles a set of elements to reach a theoretical consensus on the CE concept that resulted in a monitoring framework with indicators obtained with already available data linked to the different phases of a CE (European Commission, 2018). In addition, there are other indicators that follow this trend that were developed at national level in China (Geng et al., 2013) or are being proposed in France, Spain, Netherlands which could improve CE assessment (Llorente-González and Vence, 2019). Thus, the indicators proposed by the EC or other national-level institutions at the macro level somehow found a balance between simplification in measurement and comprehensiveness in addressing CE strategies as suggested by Iacovidou et al. (2017).

Companies as part of the micro level wherein indicators are neither fully developed nor adopted (Saidani et al., 2019b) will greatly benefit from using existing indicator created with already available data and based on a CE concept agreed upon with stakeholders (European Commission, 2018; Llorente-González and Vence, 2019). An approach that gathers indicators elaborated at macro level where a conceptualization of CE supported with indicators to track progress on CE strategies but adapted to companies is preferable.

This option is practical rather than creating or selecting indicators from multiple authors as they might contribute to confusion due to a conceptual bias which in some cases assess one-dimension of circularity or are not able to measure every CE strategy (Moraga et al., 2019; Parchomenko et al., 2019). Thus, the main objective of this study was to advance the indicators currently found in the literature, particularly at the macro level by introducing improvements according to the context in which they are applied, in this case, being applicable at the micro level (companies). Moreover, the indicators were tested in companies to prove their suitability for CE assessment.

The paper is structured as follows: section 2 offers the review of the literature regarding indicators for measuring CE actions. Section 3 explains the methodology used to select and adapt certain indicators in order to measure companies in their effort to reach 'circularity'. Section 4 discusses the results obtained in companies when the indicators that have been refined and adapted to this level are tested. Section 5 delivers some conclusions with regard to the indicators proposed in this study and further research.

2. Literature review

This literature review consisted of a bibliometric analysis, with the aim of observing what elements have been considered by researchers when measuring CE. The Web of Science Core Collection (WOS) which is regarded to be the most typically used and robust sources for bibliometric analysis (Kamalski and Kirby, 2012) was employed to carry out this analysis. Topics such as CE and indicators were used in the search query that resulted in 377 papers. The outcome of the search was then translated to a plain text document and processed in the Bibliometrix software. This open-source software follows a standard workflow for bibliometric analysis that brings accuracy as it delivers objective results built on statistical measurements from scientific literature (Aria and Cuccurullo, 2017).

Then, in order to grasp the main themes and trends regarding the scientific literature on CE indicators a relation among a conceptual network made up of keywords to identify thematic networks was represented through a thematic map as observed in Fig. 1 (Morris and Van der Veer Martens, 2008). This map consisting of a bi-dimensional matrix where axis are function of centrality and density of the thematic network serves to display emphasis to different themes emerging from the scientific literature.

In the thematic map, each bubble symbolizes a clustered keyword network; the bubble name is the word from the cluster with the highest occurrence value, and the size is proportional to the occurrences of the cluster words and the position is set according to the centrality and density of the Callon cluster (Aria and Cuccurullo, 2017). So that, density (from bottom to top) can be interpreted as a measure of theme's development and centrality (from left to right) can be interpreted as the significance of the theme in entire research field (Cobo et al., 2011).

Based on Fig. 1, the term 'indicators' as a central topic of this research appears as a transversal theme due to its importance in the entire research field. The same happens to the term China which suggest according to Fig. 1, that the term has become a motor theme which can be understood as a measure of the theme's development. This explains the position of China with regard to indicators created to measure progress on CE strategies following the CE's national policy established in this country (Geng et al., 2013).

The presence of the topic 'life-cycle assessment' underlines that the theme has been highly developed as the majority of studies have included specific CE indicators focused in end of life strategies (Di Maio and Rem, 2015; Figge et al., 2018). The theme 'energy' is represented as a highly developed and important theme which highlights indicators targeted on eco-efficiency (Geng et al., 2012b; Setchi et al., 2016). Nonetheless, the theme 'performance' indicates that the topic is neither fully developed nor significantly explored in order to consider it as a transversal theme. Consequently, this could explain that current CE indicators are not adequate to measure performance on every CE strategy (Moraga et al., 2019).

Regardless of the lack of standardized indicators to measure performance, a handful of tools and frameworks at the systems, company and product levels are providing metrics to assess circularity. Most of CE indicators have been published in recent years, which provides no timeframe in which to measure the success of CE actions. Many of these CE indicators are still in the pilot phase (Walker et al., 2018). Studies like the one proposed by Pauliuk (2018) offered a dashboard of quantitative system indicators that organisations could implement in order to become aligned with CE standard BS 8001:2017. However, as the author noted, organisations are uniquely responsible for choosing their own CE indicators, so this dashboard of indicators has fragile links to quantitative assessment frameworks.

The Material Circularity Indicator (MCI) proposed by the Ellen MacArthur Foundation (2015) calculates the quantity and intensity of circular and restorative flows at the micro level. The tool was also designed to benchmark industry's performance. Huysman et al. (2017) established an indicator to quantify the CE performance of various plastic waste treatment options based on the technical quality of the plastic waste stream. Di Maio et al. (2017) set out Value-based Resource Efficiency (VRE) indicator to evaluate the efficiency of resources on a CE based on the concept of resources returned after its end-of-life and then reincorporated into the market. A similar market-focused approach was addressed by Linder et al. (2017), in which a recirculated economic value to total product value approach was recommended as a circularity metric.

Authors such as Franklin-Johnson et al. (2016) have introduced the longevity indicator, which contributes to the understanding of material retention based on lifetime considerations. The indicator is calculated with three components: initial lifetime, earned refurbished lifetime and earned recycled lifetime. Other indicator tools such as the Circular Economy Toolkit (CET) and the Circular Economy Indicator Prototype (CEIP) assess products' circularity performance based on life-cycle thinking (WBCSD and Climate-KIC, 2018).

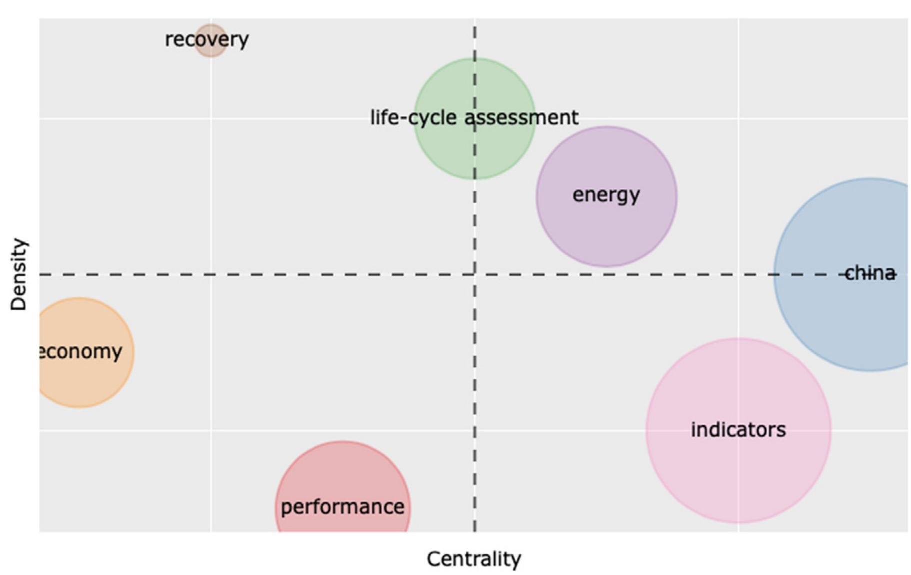

Fig. 1. Thematic map of CE indicators sorted by keywords.

While some metrics measure the contribution of material recirculation or are comprehensively related to the performance of a product rather than a company (Circle Economy, 2018; Huysman et al., 2017), they fail to associate circularity with other critical variables, including job creation, competitive advantage, and environmental sustainability. Such association is crucial for a CE transition that is understood as a total paradigm shift from an established but not efficient economic model (Linder et al., 2017; Vanessa Prieto-Sandoval et al., 2018). In contrast, the EC released a set of indicators in order to merge all the variables mentioned above and guide successful CE transition; the indicators were selected based on how they perform in terms of the RACER criteria (European Commission, 2018). The RACER (relevant, acceptable, credible, easy, and robust) criteria has been recommended to define and select indicators (Eisenmenger et al., 2016).

The indicators proposed by the EC aim to assess and track progress with regard to the CE strategies announced by the European Union in the 2015 CE action plan (European Commission, 2018) measuring four areas linked to the different phases of a CE, as shown in Table 1: a) production and consumption, b) waste management, c) secondary raw materials and d) competitiveness and innovation. As such, the EC released 10 indicators, some of which break down further into a set of sub-indicators, based on existing official statistics from Eurostat and supported by other official sources. Some indicators, such as green public procurement and food waste, are included even though a methodology has not yet been defined.

The significance of the indicators proposed by the EC is to show whether several policy initiatives undertaken by member states are successful in terms of resource efficiency in a CE. However, this set of indicators has been rebutted for being immensely engaged with the Commission's strategic priorities for material aspects such as self-sufficiency and recycling, overlooking the systemics implications of the concept (Llorente-González and Vence, 2019).

In this regard, at the macro level some others CE assessment frameworks in the form of indicators have been initiated in China (Geng et al., 2013) or have been proposed in European countries such as The Netherlands, France, Spain and Poland (Avdiushchenko and Zając, 2019). Although, at a national level, China refers its indicators on materials' recycling and waste generation, it also includes indicators of energy and water use. Another proposal developed in Spain includes among others an environmentally broader set of metrics, such as energy efficiency, use of renewable energy and water sources and carbon intensity.

There are several indicators in the literature that do not comprise all the critical variables associated with a CE (Linder et al.,

Table 1
Indicators released by the EC (2018).

Areas of a CE	Indicators and sub-indicators	Description
Production and consumption	**EU self-sufficiency for raw materials**	This describes the reliance within the EU on critical raw materials from imports.
	Green public procurement	This reflects the share of public procurement, which includes environmental criteria.
	Waste generation	
	Generation of municipal waste per capita	This is the amount of municipal waste generated (households, businesses, offices, and public institutions) and then collected by or on behalf of municipal authorities.
	Generation of waste excluding major mineral waste per GDP unit	This captures the waste generated in a country, excluding major mineral waste.
	Generation of waste excluding major mineral waste per domestic material consumption unit	This differs from the previous indicator, as domestic material consumption (DMC) is used as denominator. The DMC reflects the quantity of raw material extracted from the domestic territory.
	Food waste	This indicator is under development.
Waste management	**Recycling rates**	
	Recycling rate of municipal waste	The recycling rate is the share of recycled municipal waste in the total municipal waste generated.
	Recycling rate of all waste excluding major mineral waste	This is the share of waste that is recycled divided by all waste treated in a country, excluding major mineral wastes.
	Recycling/recovery for specific waste streams	
	Recycling rate of overall packaging waste	This covers all the waste packaging materials from products used for lifecycle of goods, excluding production residues.
	Recycling rate of plastic packaging waste	This is the total quantity of recycled plastic packaging waste in the plastic packaging waste generated.
	Recycling rate of wooden packaging	This is the total quantity of recycled wood packaging waste divided by the total quantity of generated wood packaging.
	Recycling rate of electrical and electronic waste (e-waste)	This is obtained using data from the collection rate and the reuse and recycling rate set out in the Waste Electrical and Electronic Equipment (WEEE) directive.
	Recycling of bio-waste per capita	This describes the ratio of composted/digested municipal waste.
	Recovery rate of construction and demolition waste	This describes the ratio of construction and demolition waste that is later prepared for reuse or recycling.
Secondary raw materials	**Contribution of recycled materials to raw material demand**	
	End-of-life recycling input rates	This determines the amount of material reintroduced into industrial processes from recycled material.
	Circular material use rate	This quantifies the ratio of the amount of secondary raw materials to the total material consumption.
	Trade in recyclable raw materials	This is the volume of selected wastes and by products that are traded within and outside EU borders.
Competitiveness and innovation	**Private investments, jobs and gross value added related to circular economy sectors**	
	Gross investment in tangible goods	This determines the investment in tangible goods in the recycling, repair and reuse sectors.
	Number of persons employed	This is the number of employees working on CE-related activities within the boundaries of a company (supply chain partners excluded).
	Value added at factor cost	The scope is for the CE sectors.
	Number of patents related to recycling and secondary raw materials	This is linked to patents related to recycling and secondary raw materials.

2017), or at least consider commonly used criteria for performance indicators (Saidani et al., 2019b). Even though, the complexity of CE is clear in terms of developing indicators, this also implies a need for a set of multidimensional indicators instead of a single one (Cayzer et al., 2017). Thus, there is a need to propose indicators to assess different cross-sectors businesses (Pieroni et al., 2019).

3. Methodology

As previously explained, there is not a commonly accepted set of indicators at the micro level that assess companies to ease the transformation to a CE model. However, existing indicators that guarantees simplicity and effectiveness can be found at the macro level (European Commission, 2018; Geng et al., 2013; Llorente-González and Vence, 2019). Indicators at the macro level, therefore, should be adapted at the micro level of CE implementation due to their proven usefulness to assess circularity (Iacovidou et al., 2017).

This research carried out an exploratory study to formulate the indicators suited to the micro level based on existing literature, adapted through experts' interviews and then tested in companies through an empirical work to evaluate their appropriateness with regard to measuring CE actions (Kjaer et al., 2018). The exploratory study was used as it offers a more detailed view of the subject to explore a problem and gather information about it to build the hypothesis (Yin, 2015). A mix of research methods (e.g. semi-structured interviews and surveys) to seek suitability of CE indicators for organisations were applied as suggested by Rossi et al. (2020).

As shown in Fig. 2, a series of steps were taken to advance the existing indicators for assessing CE at the micro level (companies). Firstly, a thorough desktop research was carried out to filter the most comprehensive set of indicators to assess circularity, particularly at the macro level. Secondly, an adaptation step was undertaken based on the indicators analysed in the previous step because the focus of this research was in adapting these indicators to the micro level.

The semi-structured interview method was used in this step as a data gathering tool to observe which of these indicators selected were suitable at the micro level according to interviewees' responses. The selection of this qualitative interview research approach was due to gain information about the experiences of individuals in companies (DiCicco-Bloom and Crabree, 2006). The semi-structured interviews were carried out with 4 experts in industry, as they had first-hand knowledge of the operations within companies (industrial association employee, consultant and/or former manager). All the experts were selected based on their practical experience such as their involvement in CE related projects either from the academia or industry as a key aspect in their selection to elaborate on indicator's suitability as suggested by Domenech et al. (2019).

Thirdly, once the indicators were adapted, their appropriateness in companies were determined. This was done through exploratory surveys, in order to gather all the information required to calculate and analyse CE actions within companies. This sort of survey helps to identify the notions of and basis for measurement and to develop an understanding of a topic (e.g. CE indicators), and as such they are very useful for early stages of research (Malhotra and Grover, 1998).

A questionnaire was developed and sent it to 31 companies, most of whom were members of a recycling cluster, to be completed online. The companies are all SMEs and represent a range of industrial sectors in the Basque Country, Spain. Seventeen companies completed the questionnaire; the respondents were the people in charge of gathering the indicator data in each company, which made it possible for this research to check the appropriateness of the indicators.

4. Results and discussion

The indicators released by different government bodies (e.g. the EC, Chinese government, Spanish Ministry for Ecological Transition and so on) were studied for this research. It was found out that the indicators released by government bodies may serve to assess circularity in companies. This is due to the fact that these indicators track progress on CE actions when a systematic approach is considered, outweighing other indicators reported in the literature review in terms of coverage as mentioned before. Most of this set of indicators were found to comprise critical variables that should be measured in a CE, examples being renewable inputs, upcycled materials and recycled components, sustainable inputs and jobs

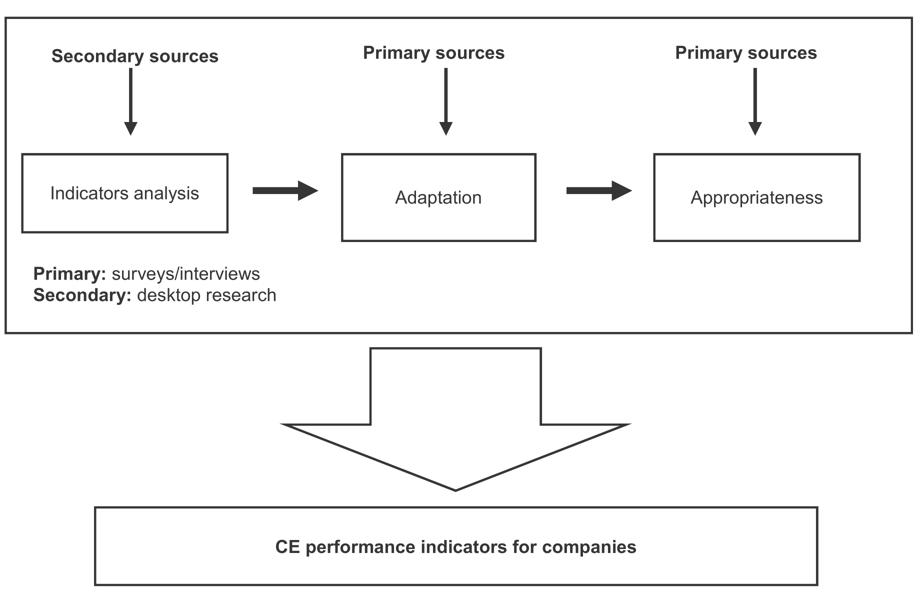

Fig. 2. Research design and data sources.
Source: authors' elaborated

creation (Di Maio et al., 2017; Linder et al., 2017). This set of indicators, particularly the EC's indicators follow the RACER criteria (relevant, acceptable, credible, easy, robust) for evaluating the appropriateness of these indicators (European Commission, 2018; Saidani et al., 2019b).

The EC's indicators may also fall into the category of leading indicators. According to Pojasek (2009), this type of indicator can be used to plan and monitor the effectiveness of proposed actions and provide guidance, thereby allowing the possibility of making adjustments and improving the solution, which is the exact aim of the EC's indicators. Some studies have pointed out that using leading indicators for performance measurements is advisable, as they deliver insight into the organisation operation or a product potential impact and provide warnings about future performance (Kravchenko et al., 2019; Morioka et al., 2016). The indicators set by the EC may serve as the core for a set of indicators repurposed at the micro level. Nevertheless, indicators of this sort were created for nationwide purposes, and therefore, an adaptation is required at the micro level.

4.1. Adaptation

As pointed out previously, the EC proposed a total of 21 indicators. For this study, they were reviewed for viability at the micro level, following the interviewed experts' judgment about their applicability to the business sector. The experts reported that "most indicators created by the EC were not applicable to companies as written, but they should be modified so they could be applied". The experts deemed that there were some indicators that shouldn't be used at the company level at all as shown in Table 2.

In the first stage of this process, the experts claimed that "ten of the 21 CE indicators were determined to not be measurable at the company level". With regard to the indicators that experts deemed as not being applicable at the company level, the food waste indicator (Table 1) was still under development by the EC, and the trade in recyclable raw materials indicator was conceived as being applicable only at the state or a regional level.

The indicators for the recycling rate of electrical and electronic waste (e-waste) and the recovery rate of construction and demolition waste were not viewed as applicable because the data requirements for building up an indicator only targets particular industry sectors and omits the overall activities of most companies. In these cases, because the indicators are strongly related to specific industry sectors, they were not considered because the aim of this study was to ask as many companies as possible about their circular actions; thus, including those indicators would be a reason to exclude many companies.

In relation to other indicators, such as generation of municipal waste per capita, recycling of bio-waste per capita and recycling rate of municipal waste, they were not determined to be applicable. This is because the population and municipal or organic waste data needed to measure such indicators is not under a company's control and it would require data from municipalities. The recycling rate of overall packaging waste was also not included since recycling packaging information is a waste stream managed by waste management companies which outsource this task from companies. This means that overall packaging waste with high recyclability (e.g. paperboard, tetra brik, glass jars) is mixed with overall packaging's low recyclability waste (e.g. plastic wrappers, office packaging, etc.) in facilities where companies are not able to keep traceability.

The end-of-life recycling input rates indicator estimates recycling's input to materials demand per type of material (European Commission, 2018). Hence, the primary material flows, processed material flows, and secondary material flows are mandatory to calculate the indicator. This entails the definition of system boundaries and flows for the calculation of each of the companies. Therefore, the quality of data varies from company to company, which makes data collection time-consuming, complex and difficult to compare. The difficulty in collecting quality data was also considered for the value added at factor cost indicator. The calculation of the gross added value of the circular economy to certain goods may vary from company to company given the subjectivity of the information required. Thus, the calculation would be also difficult to compare. Consequently, both indicators were disregarded for this research according to the experts' judgement.

Until this point, "the indicators presented should not be considered", according to the expert's opinion. However, the ten indicators left in this study fit the company context in a CE (micro level) based on the same responses given by the experts. Of the ten remaining indicators, they were deemed to be applicable at the micro level, though first they would need to be refined so they would be aligned with the company scenario. Hence, some key aspects (e.g. the calculation) needed to be refined, as detailed in

Table 2
Applicability of indicators according to experts' opinion.

Areas of a CE (European Commission, 2018)	Indicators and sub-indicators	Applicability to companies
Production and consumption	EU self-sufficiency for raw materials	Yes
	Green public procurement	Yes
	Generation of municipal waste per capita	No
	Generation of waste excluding major mineral waste per GDP unit	Yes
	Generation of waste excluding major mineral waste per domestic material consumption unit	Yes
	Food waste	No
Waste management	Recycling rate of municipal waste	No
	Recycling rate of all waste excluding major mineral waste	No
	Recycling rate of overall packaging waste	No
	Recycling rate of plastic packaging waste	Yes
	Recycling rate of wooden packaging	Yes
	Recycling rate of electrical and electronic waste (e-waste)	No
	Recycling of bio-waste per capita	No
	Recovery rate of construction and demolition waste	No
Secondary raw materials	End-of-life recycling input rates	No
	Circular material use rate	Yes
	Trade in recyclable raw materials	No
Competitiveness and innovation	Gross investment in tangible goods	Yes
	Number of persons employed	Yes
	Value added at factor cost	No
	Number of patents related to recycling and secondary raw materials	Yes

Table 3. For example, indicators such as waste generation asked for companies' revenues instead of GDP. The recycling rate was calculated based on specific waste streams (plastic, paper and paperboard waste) and not only constrained to packaging waste as a whole. The circular material use rate indicator, whose aim is to demonstrate implementation towards a circular system, gathered secondary material consumption statistics in companies following the categories described by the EC (European Union, 1994).

Whereas the still-under-development food waste indicator was eliminated, green public procurement, also under development (European Commission, 2018), was created exclusively for this study. The proposal for this new indicator rests on the grounds that it may cover the majority of industrial activities at the micro level rather than a single industry sector (i.e. the food industry). This new indicator was rebranded as 'CE procurement', following the guidelines on the criteria that are applicable to this sort of procurement (European Commission and ARCTIK SPRL-Environmental Communications, 2017).

Having refined the applicable indicators, the indicators were then grouped under competitiveness and innovation, linking the CE strategies performed in terms of investment, job creation and patents. However, to fully link circularity and other critical variables, three new indicators were added. Those indicators are energy productivity, water consumption productivity and green energy consumption, which were based on the guidelines provided by the Ministry of Ecological Transition (MITECO, 2018). These indicators were added as they are intended to measure productivity and eco-efficiency in natural-source inputs, and thus when pieced all together they comprise nearly all the critical variables associated with a CE (Linder et al., 2017).

4.2. Appropriateness

This section discusses the results of the survey. The set of indicators proposed in this study at the micro level is composed of the 14 indicators (Table 3) that were determined to be applicable in a company context (micro level) and highly oriented to CE practices as regards recycling, reuse, flow circularity information, CE finance investment and natural resource inputs. In order to assess the circular actions with the proposed indicators, a 21-questionnaire survey was administered to companies to obtain a quantitative measure of their circular strategies if implemented. Subsequently, the information described above was consolidated in the form of indicators in order to understand the business situation with respect to the CE.

It is worth noting the great effort that companies have had to make when it comes to providing information, since it is not a questionnaire that they can answer immediately; many questions required searching within the company, and sometimes that meant involving several people. A total of 17 companies participated in the survey of CE; 11 of the companies belong to a recycling cluster. The 17 companies represent different industrial sectors that, on average, have a revenue of more than 50 million euros. Seventeen per cent of the surveyed companies identified their industrial activity as taking place in the mechanical and electrical engineering sector, while 36% of the companies identified themselves as working in the sectors of construction, production of basic metals or recycling, remanufacturing and reuse. This indicates that more than half of the companies surveyed have the potential to generate some type of waste that serves as a resource to another company.

When the information from the survey was analysed, some of the indicators, such as self-sufficiency for raw materials, did not provide any helpful data. The list of critical raw material data that companies were asked to gather in order to complete the indicators was the same as the list released by the EC (European Commission, 2018). The lack of data reported for this list by companies might be explained by the fact that "companies in the area do not trade with this sort of material", which is mainly rare earth metals imported from outside the European Union according to some respondents when asked on the matter and it is beyond the scope of this study.

In Fig. 3, low CE procurement is expressed in the low rate of purchases that have criteria for eco-design, eco-labelling,

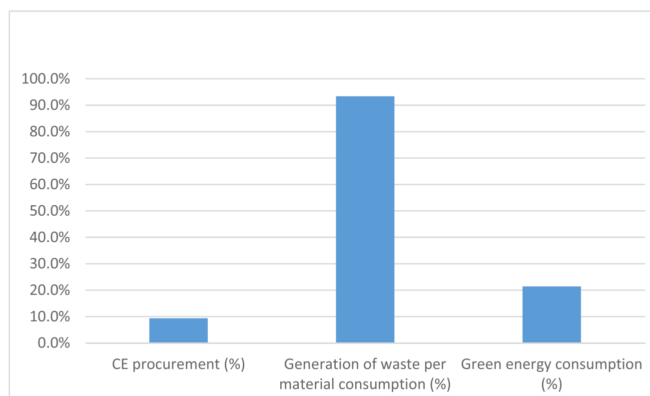

Fig. 3. Production and consumption indicators.

Table 3
Indicators developed and their calculation.

Areas of a CE (European Commission, 2018)	Refined indicators	Calculation
Production and consumption	Self-sufficiency for raw materials (%)	*1-(net) import reliance*
	Percentage of CE procurement	*[CE procurement (€)/total procurement (€)] x 100*
	Generation of waste per € (kg/€)	*[generation of waste/revenues]*
	Percentage of generation of waste per material consumption	*[generation of waste (kg)/materials consumption (kg)] x 100*
	Energy productivity (kWh/€)	*energy consumption (kWh)/revenues (€)*
	Percentage of green energy consumption	*[green energy consumption (kWh)/total energy consumption (kWh)] x 100*
	Water consumption productivity (m^3/€)	*water consumption (m^3)/revenues (€)*
Waste management	Percentage of recycling rate of all waste	*[waste recycled (kg)/generation of waste (kg)] x 100*
	Percentage of recycling rate of plastic waste	*[plastic waste recycled (kg)/generation of waste (kg)] x 100*
	Percentage of recycling rate of paper and paperboard	*[paper and paperboard waste recycled (kg)/generation of waste (kg)] x 100*
Secondary raw materials	Percentage of circular material use (CMU) rate	*[secondary materials (kg)/material consumption (kg)] x 100*
Competitiveness and innovation	Percentage of CE investment	*[CE investment on tangible goods (€)/total investment on tangible goods (€)] x 100*
	Percentage of CE jobs	*[CE jobs/total jobs] x 100*
	Percentage of CE patents	*[CE patents/total patents] x 100*

biodegradable and/or recyclable packaging, re-manufacturing, reuse or prevention and reduction of waste (9.4%). As can be seen, the companies are not taking advantage of the opportunities of a CE, and perhaps the necessary measures have not been taken to reach this point, despite having advantages in their production processes (Vanessa Prieto-Sandoval et al., 2018).

Also, the companies in the sample generate 0.35 kg (Table 4) of waste per euro invoiced, with the recycling, remanufacturing and reuse companies being the ones that have more weight in this indicator. This might be related to the quantity and the quality of the input they receive as raw material to be processed, which implies greater losses in the process, which are inherent to the business in which they operate, wherein the quality of the input may be lower compared to a virgin material of similar characteristics. Though, this indicator is simple, transparent and easy to measure, authors such as Iacovidou et al. (2017), propose selecting metrics suited to assess resource recovery from waste to optimise the multi-dimensional value of waste recovered in a CE.

The percentage of waste generated by materials consumed is 93.4% which can be considered as a clear operational inefficiency. Nevertheless, this is partially explained in companies wherein overall waste records are kept in their monitoring and control documents including the waste that is also generated through handling their suppliers' waste and not used as raw material (plastic packaging, paperboard, and so on).

This would indicate that there is an excess of waste that is not generated voluntarily, a situation that could either be improved through alliances with other companies that could receive excess waste as materials in their processes or receive prior treatment and then be offered as by-products as suggested by Aid et al. (2017). Although there are materials that can be declared as by-products for commercialization, others may need additional handling or treatment before being converted into 'food' for other companies.

Regarding the indicator of energy productivity (Table 4), the greatest contribution is in those industries that are related to construction, chemical industries and production of basic metals. This sector is characterized by having a high energy demand and a high processing of virgin material, which notably increases energy consumption and therefore, the indicator. This situation could be balanced by increasing the consumption of green energy, since, according to the surveys, only 21.4% of them consume green energy from the total energy matrix used in their production process.

The water consumption productivity indicator corresponds to efficiency of this resource, yielding a consumption of 0.002 m^3 of water for each euro invoiced. In general, no company or industrial sector contributed much to the calculation of this indicator. Although there are companies with low water consumption, a high consumption of this resource is more related to the food industry, which is a sector not represented in this study.

Despite of not being included in the EC indicators framework, the incorporation of energy and water indicators proved their usefulness in the set of indicators proposed for this study. The appropriateness of these indicators compared to the self-sufficiency for raw materials indicator which was ruled out showed a focus heavily based on a material dimension from the EC. Llorente-González and Vence (2019) found that leaving this sort of indicators aside will not reflect a comprehensive and systemic character of a CE and it might seem contradictory from the shift of paradigm in production and consumption.

This study identified two types of materials that may be subject to this commercialization or a reduction (Fig. 4). These are cardboard/paper materials and plastics, whose generation rates per material consumed were 6% and 3.6%, respectively. The percentage of waste generated for these particular materials can be considered to be low, though, the benefits of making the transition to a CE should be highlighted, since this would mean the waste of these common materials would cease to exist and it would instead be exploited in a company or as input for other organisations. In particular, the waste streams quantified for this study could shed some light on the importance of enacting the basis for resource recovery in a CE to decouple industrial output from primary resource consumption (Gregson et al., 2015) as these streams were quantified in all the companies surveyed. At the micro level it could be useful to search for the most common raw material that is also of great economic importance to companies that are vulnerable to supply disruption in a regional area to measure the benefits of different waste valorisation options (Corona et al., 2019).

The rate of CMU (Table 4) is high compared to the other indicators which indicates that companies are using secondary material as part of their production processes and replacing part of the virgin material consumed with material that has been reintroduced to the system. Although the investments made have been appreciably low, in the manufacturing area the necessary measures towards a CE have been taken. Perhaps an increase in the indicators of purchase and investment in CE would increase the CMU indicator, contributing to the closing of the loops of materials, energies and natural resources (Corona et al., 2019).

The companies allocate scant resources to the acquisition of goods and supplies related to the CE. For example, only 20.7% of companies have purchased technologies for wastewater treatment, waste or technologies with a potential or indirect contribution to the mitigation of greenhouse gas emissions compared to the total investments made in 2017. Additionally, the companies reported that around 24.1% of the workforce performs some activity related

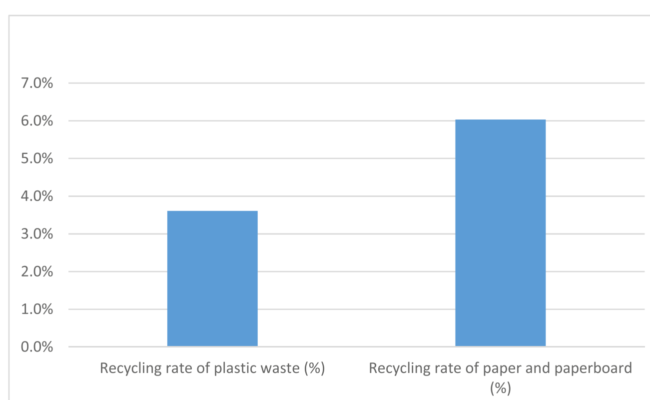

Fig. 4. Waste management indicators.

Table 4
Results from indicators in some areas of a CE.

Areas of a CE (European Commission, 2018)	Indicators	Result
Production and consumption	Generation of waste per € (kg/€)	0.35
	Energy productivity (kWh/€)	2.26
	Water consumption productivity (m^3/€)	0.002
Secondary raw materials	Percentage of CMU rate (%)	39.3

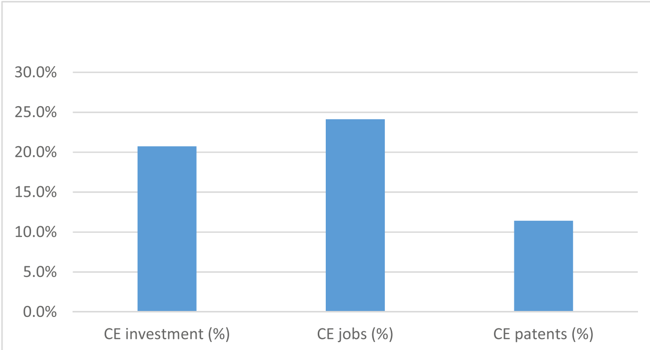

Fig. 5. Competitiveness and innovation indicators.

to the CE. Indeed, this small amount of human capital dedicated to a CE directly impacts the little innovation and development of products and services, which is crucial in a transition to this new model (Ormazabal et al., 2018). Because of this, the percentage of patents in a CE might be low (11.4%), as shown in Fig. 5.

Companies have not taken full advantage of all the opportunities present in a CE, and perhaps the necessary measures have not been executed yet, despite having advantages in their production processes (see CMU indicator). In addition, much of this commitment is not fully manifested in trends toward circular business models, as can be seen in the low investment in human capital (Fig. 5). So, companies are prevented from obtaining benefits through symbiosis programs with other companies that are willing to use by-products or secondary materials in their production processes.

Furthermore, an increase in purchase and investment budgets in CE actions could help to close the loops in materials, energies and natural resources through innovation and development programs (Smol et al., 2017). These indicators might be able to represent the systemic nature of CE, although, they are lacking robust measurement on added economic value built on current sustainability assessment framework such as life cycle assessment (Corona et al., 2019). However, as they were presented, these indicators evidences an idealized CE than a mere material recirculation (Llorente-González and Vence, 2019).

5. Conclusions

The development of indicators is a key accelerator for circularity that allows data-driven decisions to be made and tracked. This data-driven approach will help to weigh the holistic benefits of CE strategies and may serve as a baseline to analyse the value of a transition to a CE. Companies adopting metrics to calculate circularity do not necessarily mean starting from the very beginning which will be critical to ensure alignment with the goals that companies already have in place.

Therefore, the objective of this study was to develop and analyse applicability of indicators aimed at assessing CE actions at the micro level based on existing metrics that guarantees simplicity and effectiveness. Overall, the indicators proposed in this study were applicable at the micro level based on the companies' responses. This fact demonstrated that the indicators serve the purpose of being applicable to companies regardless of the type of economic activity they were in. Although the conceptualizing of circularity varies widely from companies, this cross-sector metrics based on common conceptual framework will enable companies to at least speak the same language. Furthermore, with the support of these indicators, companies gain help in tracking CE actions in order to arrive at best managerial practices.

Finally, it is recommended that the CE indicators focused on the methodology proposed in this study should be studied across different industrial sectors in order to observe performance in companies. Nevertheless, our study was limited to manufacturing companies. In order to enhance these indicators, a robust baseline must be set to monitor improvements in transitioning to a CE including different sectors such as banking, services among others to assess the applicability of this set of indicators. This monitoring might help companies to track their actions and strategies in the medium and long term and be more aligned with a CE model. This will lead to consistent measurement frameworks that will enable data-driven decision-making and progress-tracking, and ultimately justify the value of a CE model.

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CRediT authorship contribution statement

J. Rincón-Moreno: Writing - original draft, Data curation. **M. Ormazábal:** Conceptualization, Methodology. **M.J. Álvarez:** Writing - review & editing. **C. Jaca:** Conceptualization, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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