Discover Sustainability

Research

A forest companies typology regarding their contribution to circular economy: a sustainability reporting-based analysis

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Abstract
Relatively recently, the residuals of forest industry have been considered very important and useful to be reused through bioeconomy and circular economy practices in order to reduce the use of non-renewable natural resources. The majority of current studies have been based on interview protocols and questionnaire-based surveys to examine how managers of forest industry contribute to sustainable development and circular economy. Despite the usefulness of these surveys, there is a degree of subjectivity in the respondents' responses and an orientation to what forest companies propose to do in the circular economy. To overcome the weaknesses of previous research, this paper aims at drawing appropriate information from sustainability reporting of a sample of forest companies to provide a more unambiguous understanding of the way that forest companies meet the circular economy principles. Thus, a circular economy measurement framework is developed which is based on scoring systems and GRI guidelines to draw reliable and harmonized information from corporate sustainability reporting. Furthermore, it results in a four-type company typology according to the number of the circular economy principles and the number of items they achieve for each principle such as pioneer circular company, lagging circular company, innovative circular company and infant circular company. The suggested framework is tested on a sample of 20 forest companies with higher revenue in 2022. The findings show that half of the sampled companies can be considered as infants at the CE practices, while a positive statistical relationship is revealed between forest companies' circular economy practices and their revenues.

Keywords Forest circular economy · Bioeconomy · Forest industry · Circular economy principles · GRI · Sustainability · Forestry

1 Introduction

Circular economy (CE) is a concept which gains a great momentum in the literature of sustainable development [1]. It is considered appropriate to assist in transforming the current linear production model to a circular one by narrowing, slowing and closing the loops of materials [2]. Several studies have been conducted in the field of CE that could be classified in three general categories [3, 4]. The first category puts more emphasis on examining micro-level of firms and products in which different sectors adopt CE principles (e.g. reduce, reuse, and remanufacture) to contribute to sustainable production and consumption both from firm side (production) and consumers (consumption) side [5]; the

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second category includes examples that focus on cooperation between firms [6] which exchange end of life products and materials as raw materials; the third category focuses on region, city and country level circular economy practices [7].

Another critical point of CE pertains to the selection of appropriate procedures that economic actors adopt to contribute to the technical and biological cycles. The former type (technical) of cycle includes mainly artificial materials that could be made under technical transformation (e.g. refurbish, remanufacture, reuse, and recycle) to be ready, again, for production and consumption. It is considered a good prospect for maintaining mainly non-renewable natural resources for a longer time in production and consumption phases. It may also be a good answer to issues such as strong sustainability and the rebound effect [4]. The later type (biological) of cycles pertains renewable natural resources which have the capability to sustainably return back to the production and the consumption procedures [8]. The products in the biological cycle should be designed with intention to protect safe minimum standards of renewable natural resources so as to maintain their ability to regenerate. A very good diagrammatical representation is provided by the butterfly diagram of Ellen MacArthur Foundation which shows a number of principles that are associated with technical cycle (right side of the diagram) such as share, reuse, reduce, recycle and recover, while highlight cascade use and biogas prospect of biological cycle (left side of the diagram).

To this logic, many company sectors provide direct and indirect contribution to technical cycle of natural resources by adopting several circular manufacturing strategies such as cleaner production, circular business models, waste management, disassembly manufacturing, recycling, close loop supply chains and reverse logistic, industrial symbiosis, and circular design [9]. In a more systematic way, [10] provide four types of strategies that assist companies in contributing to biological cycle of products such as physical (e.g. pressing, milling, separation, fibers separation, upgrading, fractionation, and extraction), chemical (e.g. hydrolysis, oxidation and pulping), biotechnological (e.g. anaerobic digestion, aerobic fermentation, enzymatic conversion) and combined strategies (e.g. combustion and gasification). Actually, it is very difficult to separate technical and biological cycle. Thus, the majority of studies focus on examining the contribution of companies to CE by examining the types and the number of CE principles they adopt (e.g. refuse, reduce, reuse, recycle, remanufacture and refurbish) which is known also as 'Rs' models.

Some critical points of this discussion have been transferred into the forestry sector which plays and is expected to play a significant role in the European economy, as it accounts for a fifth of the total EU manufacturing sector. This requires the harmonization of its operation with the principles of the CE [11]. This sector is concerned with a renewable resource and can contribute simultaneously in the biological and CE cycle by adopting appropriate strategies.

Although the circularity of forest companies is of great interest for sustainable development, their contribution to circular economy is nevertheless clearly less studied in the relevant literature. Circular economy and its relation to forest companies has been mainly examined through literature review studies [12, 13], interviews with experts in forest companies [14], and questionnaires to forest companies [15], methodology strategies that are subjective to these companies' views on circular economy. This fact causes a strong interest in investigating the contribution of this specific sector to the CE by examining a rather more independent source of information, the forest companies' sustainability reports. Today, the majority of these studies focus on examining only how these forest companies contribute to different aspect of sustainability such as economy, environmental and social. The findings of these studies mainly focus on identifying critical points that will be useful for understanding the relevant field without any analysis of primary data on the performance of the companies in the relevant field. The literature of the relevant field needs to record the current state of efforts undertaken by forest companies to promote bioeconomy and circular economy issues. In this sense, the necessary data should be drawn from the sustainability reports of forestry companies since they are important databases with real data on their practices in the protection of the natural environment. Thus, by using corporate sustainability reports, the objective of the present research is to answer the following research questions:

RQ1: To what extent have companies in the forestry sector adopted the principles of the circular economy?

RQ2: What techniques have been used in the forestry sector to satisfy the principles of the circular economy?

RQ3: What types of circularity are present in the forestry sector?

These research questions will be answered by extracting information from corporate sustainability reporting and through scoring/benchmarking techniques which is based on the GRI standard. Finally, it concludes on a typology regarding forest companies according to the CE principles. It is applied in a sample of 20 forest companies in the European region. The findings showed that some forest companies are classified as innovative in CE practices which follow more than the four most used principles (Reduce, Reuse, Recycle, and Recover), and three of the sampled firms are classified as the Pioneer Circular Forest Companies being the leaders in CE practices.

The rest of the paper is classified into four sections. The second section analyzes the theoretical background regarding CE and forest companies. The third section presents the methodology of the paper. The fourth section includes the results of the research and the final section describes conclusions of the paper.

2 Theoretical underpinning

Although a number of theoretical and empirical research studies have been conducted regarding CE, there is a lack of a consensus regarding its content among scholars and practitioners' cycles [16]. Exploring the multitude of the CE definitions [17], identify 114 definitions placing different emphasis on *'Rs'* strategies by replacing the 'end-of-life' thinking from production system with alternative *'Rs'* strategies such as reduce, reuse, recover, recycle. By updating their research after 5 years, [18] gather 221 definitions about CE by pointing out a strong relationship between CE and sustainable development. Many other scholars have analyzed the CE definition by focusing on CE principles (*'Rs'*), influences from international organizations (e.g. Elen MacArthur Foundation, European Union) and scientific observations [19–21].

It is important to highlight every component of CE concept: circular (C) and economy (E) (Fig. 1). The first component implies the protection and preservation of renewable and non-renewable natural resources in order to meet current and future needs of societies (Technical Cycle). This signifies that actors on production side should adopt certain strategies in order to extend the life of the non-renewable materials and avoid using 'virgin' natural resources. Furthermore, cascading use for renewable natural resources is promoted in order to use biomass in production stages as well as to eliminate waste generation (Biological Cycle). The other component is another significant aspect, implying less costs, increased revenues and profits of companies (Economy).

The analysis of the definitions and practices adopted by companies in the CE is usually made based on the principles they adopt since they indicate the degree of their contribution to the CE sector. Indeed, many scholars analyze the circular economy through the various *'Rs'* strategies with the dominant models being the *'3Rs'* (reduce, reuse and recycle) and *'4Rs'* (reuse, reduce, recycle and remanufacture) models [22]. Potting et al. [23] provide a *'10Rs'* strategy model which focuses on smarter products (e.g. refuse, rethink and reduce), improves circularity (e.g. reuse, repair, refurbish, remanufacture, repurpose) and promotes useful use of materials (e.g. recycle and recover), while it contributes to economic direction by eliminating costs of production and consumption of materials.

As presented in the international literature, forest industry contributes to both components of CE such as through bioeconomy (biological cycle) by utilizing wood waste and through 'Rs' strategies to eliminate and extend end of life of forest products [24, 25]. Forest industry contributes both to technical and biological cycle by adopting different strategies. In the biological cycle, cascading poses challenges in forecasting future environmental, social, or economic benefits within forest and related bio-based industries, particularly due to the extended life cycle of certain wood products [26].

Although it is clear that the contribution to both of these cycles is extremely important for sustainable development, nevertheless in the context of this paper emphasis will be placed on the analysis of the contribution of the forest companies to the CE for which less knowledge exists today. In this logic, [27] examine 28 forest companies which consume 83.6% of their raw materials from 'virgin' natural resources and identify that over 90% of their waste

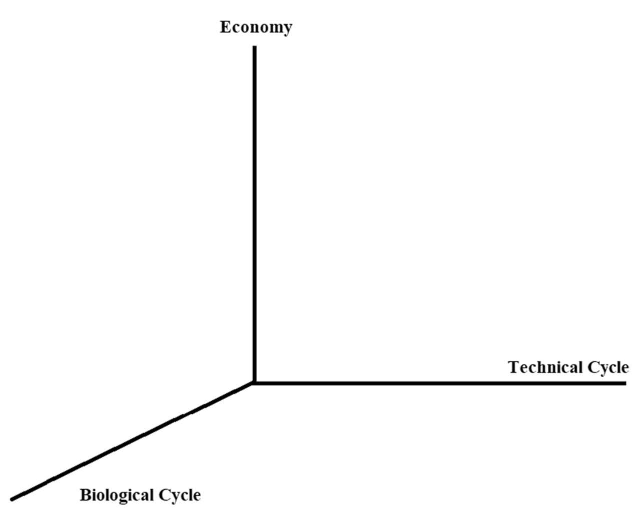

Fig. 1 Circular economy

is intended for energy recovery. In the forest sector [12] put emphasis on the effects of CE strategies on the ecosystems conservation by examining Slovak forest sector. By conducting an interview-based survey in a sample of 15 experts in the Slovak forest sector, they find a significant role of forest sector to improve wood efficient use through CE strategies and its contribution to increase capability of forest companies to substitute non-renewable resources with wood residuals which offering economic benefits for companies and protecting ecosystems.

Tedesco et al. [15], in a questionnaire-based study conducted within Brazilian forestry companies using the ReSOLVE framework, emphasize that regenerating and exchanging practices receive the highest scores for implementing CE, while sharing and virtualizing practices show lower implementation levels. They, also, highlight that challenges regarding the implementation of CE originate from issues such as employee training and awareness, shifts in behavior and organizational culture, and a general lack of interest, underscoring the significance of focusing on education and training, support from public policies, and collaboration within the market.

Similarly, [28] identify that circularity practices within the planted tree industry of Brazil, as assessed by the ReSOLVE framework, are predominantly adopted by large companies, particularly those engaged in pulp and paper production. Their survey also underscores the significant role of industrial symbiosis in facilitating the transition towards CE.

To protect the forest ecosystems, forest companies could adopt industrial symbiosis and effectively reduce waste, conserve resources, and yield economic and social benefits [29]. Moreover, they can use chemical techniques, thermal methods and nanotechnologies to extend the life span of wood materials. Some promising sectors that are expected to assist in reusing and recycling wood residuals are the construction and pulp and paper industry. By conducting two case studies [30] examined different prospects of forest companies to contribute to CE. In the former case study, they utilize questionnaire-based survey to examine the prospects of a sample of forest companies in the Kymenlaakso region which adopt CE and bioeconomy strategies to manage the amount of waste material and energy efficiency. They, also, identify some barriers to develop the concept of CE in the forest sector which are associated with the loose regulatory regime and limited demand for wide-scale cascading of solid wood in Finland. Finally, they conclude to some principles of CE that could promote cascading use of materials such as reuse of wooden packages and energy recovery.

Parallel, [14] points out that forest industry needs a long-time strategy to promote CE such as resource efficiency, recycling and closing the loop of wood materials. By conducting an interview-based survey, the researcher identifies that respondents highlight the traditional closed-loop thinking of the Finnish forest industry which reuses and recycles wood residuals. It is also identified that respondents highlight that the majority of the current discussion has a societal orientation which is alienated from the business world. Essentially, the behavior of businesses is affected from an appropriate market-based and command-and-control regime to create a competitive and concrete context in order forest companies to exploit opportunities from CE practices.

Similarly [31], conduct a study to examine how the different business sectors (e.g. construction, real estate and forest industry) through CE can reduce their impacts on biodiversity. They highlight some specific strategies like material efficiency, cascading use of wood, reuse of materials, extending buildings' lifetime which can play a critical role in creating appropriate conditions in order companies to reduce extraction of virgin raw materials. They highlight also that although the use of forest products has impact on biodiversity (in Finland where this study focus) and eliminates the use of non-renewable materials in construction industry, nevertheless it requires specific policies in order to protect biodiversity. This is a serious point since the global growing demand for wood products will obviously lead the economy to a rebound effect with more and severe consequences on biodiversity without adopting certain prevention and protection strategies.

Furthermore, [32] examine the attitude of leaders of forest industry regarding CE strategies by conducting interviews-based survey and analysis of secondary data of companies (e.g. information from websites). They identify a positive attitude of leaders to adopt '*10Rs*' principles (e.g. refuse, reduce, recycle, remanufacture and recover). Additionally, they classify forest companies in three categories according to the type of principles they adopt such as short-loops (e.g. refuse, reduce, reuse and repair), medium loops (e.g. refurbish, remanufacture and repurpose) and long loops (e.g. recycle, recover and re-mine). Similarly, [33] developed a new theoretical framework to examine cascading use with *'10Rs'* by drawing knowledge from relative literature. Many scholars have focused on examining specific circular economy principles such as wood remanufacturing [34, 35], forest recycling and recovery materials [16].

The majority of these studies focus on questionnaire-based and interviews-based survey to draw information about the CE strategies that forest companies adopt. Although their findings are very useful for scholars and practitioners, nevertheless there is a need for more empirical and accurate findings to improve scholars understanding of the behavior of forest companies in adopting different *'Rs'* strategies. One significant and appropriate way is to draw information from sustainability reports of the forest industry in which information about environmental, social and governance (ESG) practices is disclosed. These reports are adequate inventory that any type of companies' accurate and reliable information about ESG and CE is disclosed.

3 Methodology

3.1 Research structure

To conduct this research study, a new methodological framework is developed to draw information from corporate sustainability reporting, in order to estimate the level of the circularity behavior within the forest industry. It is based on four fundamental steps, as shown in Fig. 2, such as research questions development (S1), measurement technique design (S2), Matrix Typology development (S3) and data selection criteria presentation (S4) (Fig. 2). Afterwards, a data analysis has been performed to draw useful information for current literature and a discussion has been made to identify similarities and differentiations regarding the behavior of forest companies towards CE topics.

3.2 Research questions

Nowadays, as analyzed previously, there are two basic cycles in the CE thinking that forest companies can contribute in order to protect natural resources such as the biological and technical cycle. The former implies the adoption, by part of forestry companies, of bioeconomy principles that forest companies can adopt in the procedures to use natural resources in order to maintain the resource regeneration rate of renewable natural resources, while the latter suggests that forest companies can, through the principles of the CE, use end-of-life materials. The dimension of the CE in the forest sector has been less explored which is a significant trigger for this research. It is indeed a very crucial point for the current literature to shed light under a reliable evidence on the practices adopted by forest companies regarding CE. The analysis of the theoretical background shows that forest companies adopt various CE models including single or multiple CE principles (e.g. reduce, reuse or recycle). Consequently, the first scientific question that will be investigated in this research is:

First Research Question (RQ1): To what extent have companies in the forest sector adopted the principles of the CE?

Another important part of the relevant literature is the identification and investigation of the techniques used by forest companies to achieve CE principles. It is extremely important to recognize the actual practices that forest companies

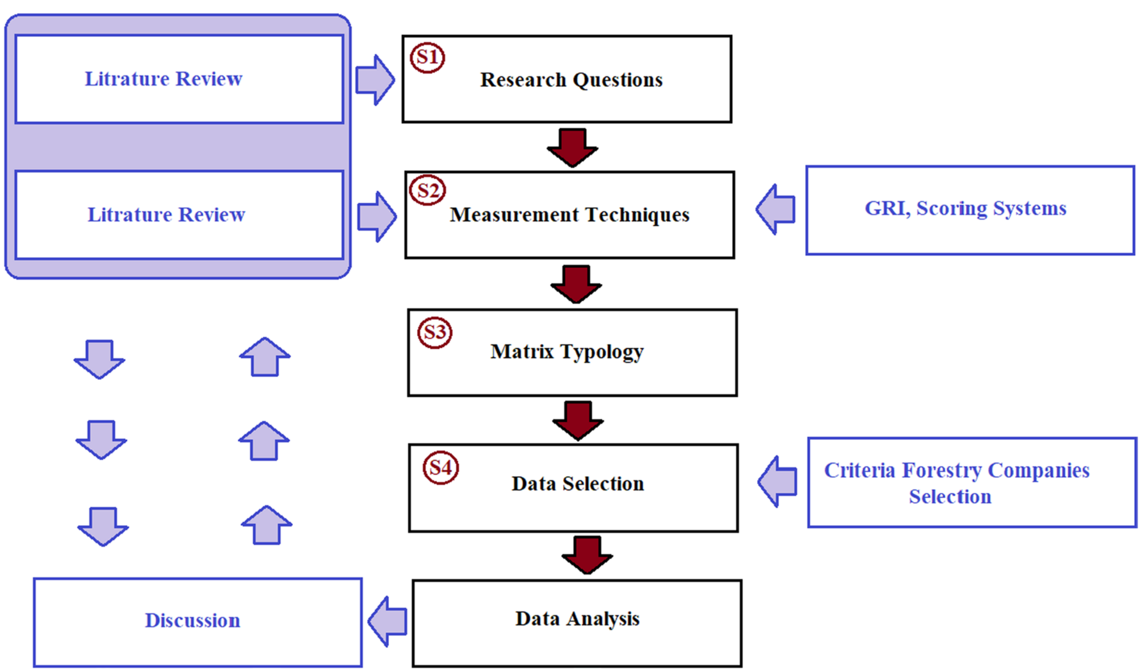

Fig. 2 Research structure

adopt to reduce, reuse, recycle and remanufacture wood residuals, rather than just examine the trends and perceptions of managers about the prospects to adopt such practices. In this sense, the next scientific question of this research is:

Second Research Question (RQ2): What techniques have been used in the forest sector to satisfy the principles of the CE?

However, the degree of integration of CE principles adopted by forest companies, as seen from the analysis of the previous theoretical background, differs among them. There are companies that have adopted one principle (e.g. reuse or recycle) and others that have adopted many more principles (e.g. *'10Rs'*). There are still identified differences within the practices adopted among companies even for the same principle of CE (e.g. for reduce). Consequently, the number of principles and the range of practices adopted by forest companies may lead to different types of classifications and investigation of these companies. In this sense, the next scientific question of this research is:

Research Question (RQ3): What types of circular behavior are present in the forest sector?

3.3 Measurement system

It is important to note that corporate sustainability reports can serve as an important inventory of information on the environmental, social and governance (ESG) performance of companies. However, the unsystematic way in which this information is disclosed in voluntary corporate sustainability reporting has led researchers to develop scoring and content analysis techniques to draw reliable information for reasons of uniformity, comparability and completeness [36, 37]. The specific techniques are based on the use of quantifiable items from the yet established information recording standards (e.g. GRI, SASBs and IR) and evaluate each information either for its content (e.g. content analysis techniques) or for its degree of completeness (e.g. scoring techniques) [38, 39]. Given the relevant literature, a three-task measurement framework was developed for the analysis of sustainability reports for CE performance. First, the *10Rs*' model was recorded from the literature, then each principle was harmonized with the guidelines of the GRI, and finally, the scoring technique for each information was developed.

The selection of CE principles is based on the research works of [17, 23, 32, 40]. The first column of Table 1 displays the principles selected in the proposed methodology. In the second column, the appropriate items from the GRI standard are described and classified per CE principle, and in the third-fourth columns, mathematical formulas are described. Finally, the Total Circular Score arisen form GRI items (TCS_GRI) indicates the score that a forest company achieves in the field of CE. The score of TCS_GRI ranges from 0 to 44, where 0 implies the min score (none CE principles and GRI indicators be adopted) and 44 represents the max score (all CE principles and GRI indicators be adopted). It is noteworthy that in case an indicator is used by a company and this indicator is related to more than one CE principles, the score is calculated

Table 1 Measurement technique

Circular economy principles	GRI standard codes	Measurement scale	Max score per principle
Refuse (RF)	308–1	**0**: when no information disclosed; **1**: when relative information disclosed	$0 \leq RF \leq 1$
Rethink (RT)	201–2, 203–2, 301–3		$0 \leq RT = \sum_{i=1}^{3} rt_i \leq 3$
Reduce (RD)	203–2, 305–5, 306 (−1,−2,−3,−4,−5),		$0 \leq RD = \sum_{j=1}^{7} rd_j \leq 7$
Reuse (RU)	203–2, 301–2, 301–3, 303–2, 306 (−1,−2,−3,−4,−5)		$0 \leq RU = \sum_{k=1}^{9} ru_k \leq 9$
Repair (RP)	203–2, 306–2		$0 \leq RP = \sum_{l=1}^{2} rp_l \leq 2$
Refurbish (RFR)	203–2, 306–4		$0 \leq RFR = \sum_{m=1}^{2} rfr_m \leq 2$
Remanufacture (RM)	203–2, 301–3		$0 \leq RM = \sum_{n=1}^{2} rm_n \leq 2$
Repurpose (RPU)	203–2, 303–2, 306–4		$0 \leq RPU = \sum_{o=1}^{3} rpu_o \leq 3$
Recycle (RC)	203–2, 301–2, 301–3, 303–2, 306 (−1,−2,−3,−4,−5), 416–1		$0 \leq RC = \sum_{p=1}^{10} rc_p \leq 10$
Recover (RCO)	306 (−1,−2,−3,−4,−5)		$0 \leq RCO = \sum_{q=1}^{5} rco_q \leq 5$
Total Circularity Score _GRI (TCS_GRI)		$0 \leq \boldsymbol{TCS\_GRI} = RF + RT + RD + RU + RP + RFR + RM + RPU + RC + RCO \leq 44$	

based on the assumption that the indicator as used by the company refers to the principle. Otherwise, the use of the indicator is not assigned to the principle.

3.4 Matrix typology

The suggested classification highlights the behavior of forest companies on CE topics. A quick, reliable and simple way to classify forest companies is the number of CE principles adopted by them and the number of items/strategies they implement for each CE principle.

This can be measured in a two-axis system where the GRI items will be measured vertically and the number of principles adopted by forest companies on the horizontal axis. Setting a limit between the mean score achieved by a company in the GRI items and the mean score achieved in the principles of the CE (Fig. 3) makes possible the distinction of four categories of forest companies according to their behavior in the CE.

These categories are as follows:

A) **Pioneer Circular Forest Companies** that simultaneously adopt five or more CE principles and achieve score TCS_GRI ≥ 22. Having achieved these scores it could be stated that the companies have a very quick adaptation to the principles of the CE and therefore they are considered pioneers.
B) **Innovative Circular Forest Companies** that have adopted five or more of the principles of the CE and achieve score TCS_GRI < 22. Companies of this category are considered innovative due to the fact that they adopt many of the principles of the CE which is a new and not mandatory concept.
C) **Lagging Circular Forest Companies** that have adopted less than five principles of CE and achieve score TCS_GRI ≥ 22. These companies present a lag regarding the principles of CE.
D) **Infant Circular Forest Companies** that have adopted less than five principles and achieve score TCS_GRI < 22. These companies seem to adopt the CE but have a low index of assimilation of the principles.

3.5 Data selection and manipulation

The study is, specifically, focused on leading companies of the forest industry, based on their 2022 revenue. They are situated in Europe. Large European companies were selected because such entities possess a potentially greater influence on the natural environment, compared to SMEs [41]. Furthermore, EU has conspicuously committed itself to matters germane to the CE influencing and countries attached to it, such as Norway and United Kingdom.

The sample has been sourced from data compiled by Statista's research dataset [42, 43] and the Sawmills database [44]. It comprises all companies sourced from those two databases that have publicly disclosed their non-financial reports for the financial year 2022. The twenty companies, subjected to analysis and processed to conduct the research, are the following: Smurfit Kappa, UPM Kymmene, Stora Enso, DS Smith, Metsa Group, Billerud, Navigator Company, Holmen, Svenska Cellulosa, Mayr-Melnhof Karton AG (MM), HS, Sveaskog, Junckers, Moelven, Norske Skog, Södra, Ence, Altri, Setra και Bergs.

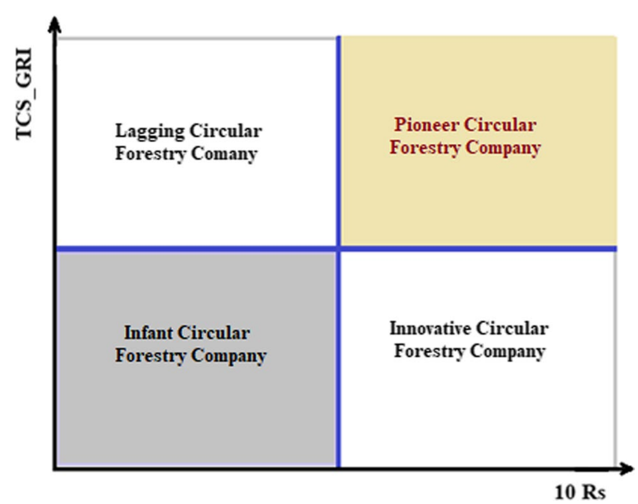

Fig. 3 A typology matrix in accordance to CE principles and GRI index

The information was drawn from the sustainability reports and annual reports, released by the companies, in the English language, for the financial year 2022. If the report wasn't composed and published in English language, then the company wasn't selected. The first author performed the content analysis, and then discussed it with the other two authors, which confirmed the findings. The data gathered were analyzed with main descriptive statistics and helped for the classification of the twenty companies to the four CE categories. Finally, the classification was related to the 2022 revenues of the companies to take an insight on the relation of CE practices and financial indicators.

4 Results

4.1 Sample analysis

The 20 companies presented a median revenue for the 2022 of 1.92 bn € (min = 0.05, max = 12.82). As expected, all of them issued information on sustainability matters. The 35% of the companies in the sample published a stand-alone Sustainability Report, while 45% of them integrated the Sustainability Report into the Annual Report. The remaining 20% of companies published either only an Annual Report, or an "Integrated Report", or a "Consolidated Non-financial Report", or a stand-alone Corporate Social Responsibility Report ("CSR Report").

4.2 Circular economy principles adoption

Regarding the circular economy principles adoption by the 20 leading forest companies, the analysis of the sustainability reports showed that all companies report that they implement the following two principles: (i) reduce, and (ii) recycle. Two more principles seem to be used almost profoundly (more than 80%) by the companies, which, specifically, are the following principles: (i) reuse and (ii) recover. By applying these principles the companies seem to take preventive and corrective measures for issues related to the management of their waste as well as the design of their packaging. Additionally, these principles seem to operate as indicators for the evaluation and measurement of circularity by companies. This is also evident in the schematic representations of the CE in the companies' reports, which include at least one of the above four principles.

However, it seems that most of the companies are not particularly familiar with the other principles of the CE. Specifically, only one company states that it applies the principle of Refusal. In particular, it has replaced typical packaging with mono-material packaging to encourage its customers to refuse packaging that is difficult to recycle and is not biodegradable. It is worth noting that mono-materials are products consisting of a single material, making them easier to separate, recover, and recycle [45]. The Repurposing principle, although not explicitly mentioned, is applied by one company, which mentions that it uses parts of products intended for disposal (e.g., pulp) to produce products with different functions (e.g., tall oil converted into liquid fuel). Additionally, the Remanufacturing principle is applied by 2 companies within the frameworks of the circularity strategies they follow. The repair principle for the design and production of sustainable packaging is followed by three companies.

Finally, two principles are not applied by any company. These are the Rethink and Refurbish principles. It is noteworthy that one company uses the words "Repair" and "Refurbish" in the definition it proposes for the circular economy, indicating its intention and commitment to applying these principles in the future. Table 2 summarizes the above information by showing the number of companies that apply each one of the 10 CE principles.

Figure 4 shows the frequency of the companies regarding the maximum CE principles they adopt according to their sustainability reports. On the x axis there is the number of ***Rs*** used by them, while on the y axis there is the absolute frequency of companies. As shown, there is only one company that adopts 7 of the 10 ***Rs***, no company adopting 6 ***Rs***, while 10 out of 20 companies adopt the main four aforementioned *Rs,* reduce, recycle, reuse, recover.

4.3 Companies circular performance

Eighteen out of the 20 companies use GRI indicators to publish information related to their performance in terms of financial, social, environmental, and governance (ESG) issues. The other two companies present sustainability information on their websites (CSR and Integrated reports respectively), without citing GRI indicators. The information derived from the tools they use, show that they only adopt two ***Rs***, namely reduce and recycle.

Table 2 Adoption of the ***10Rs*** by the leading forest companies

CE principles	Absolute frequency (N = 20)	Relative frequency (%)
Refuse	2	10
Rethink	0	0
Reduce	20	100
Reuse	16	80
Repair	3	15
Refurbish	0	0
Remanufacture	2	10
Repurpose	1	5
Recycle	20	100
Recover	17	85

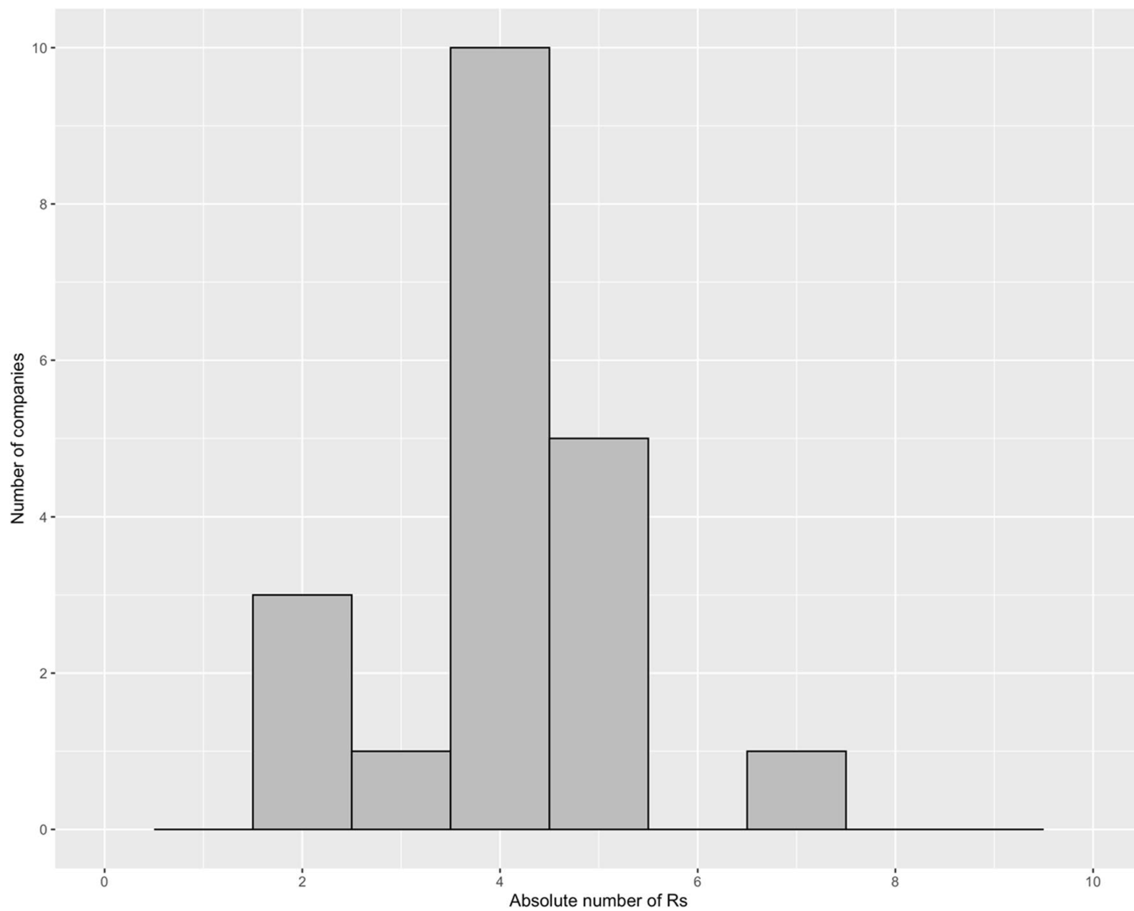

Fig. 4 Frequency of the companies regarding the maximum CE principles

In regard to the other 18 companies, the GRI Standards Set, as aforementioned, reveals that the indicators through which companies can disclose data and information regarding the implementation of circular economy methods are thirteen in number. It is noteworthy that, out of these indicators, none is used by all these companies. The most used indicator by companies, in comparison to others, is the "306–3 Waste generated" indicator (used by 70% of the sample companies). Following are the indicators "305–5 Reduction of GHG emissions," and "306–2 Management of significant waste-related impacts" (65% of the sample companies). Finally, the least used indicators are "203–2 Significant indirect

Table 3 Relation of Rs and GRI indicators in the sample of forest companies

CE principles	median TCS_GRI	% of max score
Refuse	0	0
Rethink	0	0
Reduce	3.5	50
Reuse	4	44.4
Repair	0	0
Refurbish	0	0
Remanufacture	0	0
Repurpose	0	0
Recycle	4	40
Recover	3	60

Table 4 Descriptive statistics of TCS_GRI

Parameter	Value
Mean	15.75
Standard deviation	12.00
Median	14.50
Min–Max	0.00–36.00
1st quarter	5.50
3rd quarter	28.25

economic impacts" (25%), "301–3 Reclaimed products and their packaging materials", and "416–1 Assessment of the health and safety impacts of product and service categories" used by 30% of the sample companies.

There is one company which uses all the 13 indicators, while three companies use only one indicator. On average, each company uses 48.09% of the 13 indicators. The 75% of the companies use the 86.53% of these indicators.

Table 3 shows the relation of GRI indicators with the Rs. The median TCS_GRI score achieved by the 20 companies in each CE principle is presented. The next column shows the percentage to the max possible TCS_GRI score, as indicated on Table 1.

The results show that at least half of the companies do not achieve a **TCS_GRI** score in 6 of the ***10Rs***, and on other three ***Rs*** at least half of them achieve less than half of the max score. Although not used by all the companies, the **Recover** principle has a mean score 3 out of 5 (max) which shows that at least half of the companies seem to achieve a **TCS_GRI** score more than half of the max score (they pass the threshold of 50% score).

4.4 Circular companies typology

This section presents the typology of the forest companies in the context of Fig. 3. Table 4 shows the descriptive statistics for the Total Circularity Score (**TCS_GRI**) that the companies achieved according to the methodology of Table 1.

The Table 4 shows that most of the companies are measured below the threshold of 22 which is one of the two criteria for allocating them into one of the four categories. Indeed, those that pass above the threshold are in total 6 out of 20 with scores ranging from 26 to 36.

Figure 5 shows the allocation of the companies in the Fig. 3 model by applying the methodology of Table 1. The *x* axis shows the total number of CE principles (***Rs***) the company follows, and the *y* axis the Total Circularity Score as measured for each one. The circles in Fig. 5. represent two companies (which they share the same coordinates), while the triangles one company.

Figure 5 shows that the majority of the forest companies (10 out of 20) are classified as infants in Circular Economy practices. The companies in this category follow either the four most used principles (Reduce, Reuse, Recycle, and Recover), or only Reduce and Recycle. One company follows the Reduce, Recycle, and Recover principles. All the

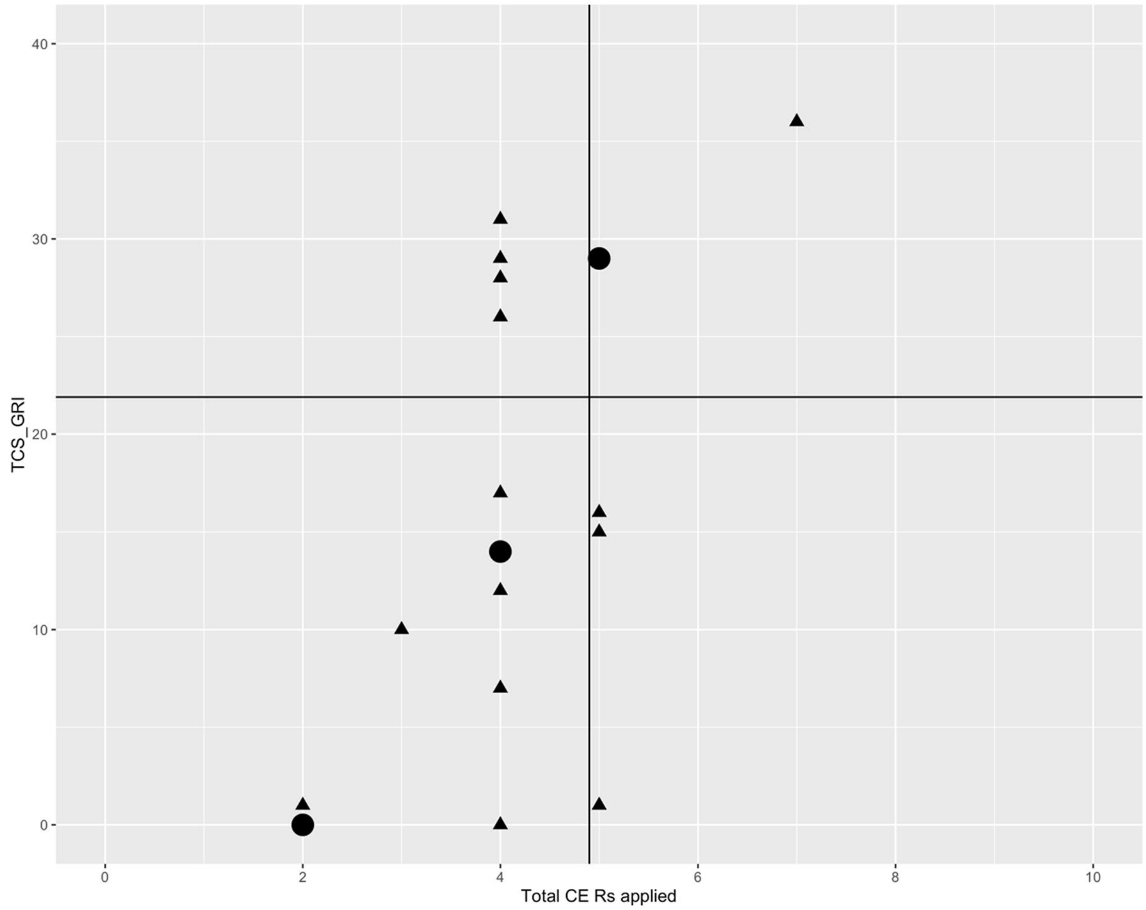

Fig. 5 Forest companies circularity typology

companies are measured a TCS_GRI ranging from 0 to 17 with the lowest scores being allocated to those companies following only two ***Rs***.

The Lagging Circular Forest Companies are four in total in this sample of 20 companies. They all follow the Reduce, Reuse, Recycle, and Recover principles and are measured higher than the 22 threshold in the TCS_GRI. The scores range between 26 and 31.

The Innovative Circular Forest Companies are three out of 20. They all follow 5 CE principles. In addition to the four most used CE Rs, each of these three companies follow each one a different R. These three Rs are Refuse, Repair, and Repurpose showing a different policy among these three innovating CE companies. Here the scores are 1, 15, and 16.

The rest three companies are classified as Pioneers in the CE practices. Two of them follow five Rs, and one follows seven Rs. The additional to the Reduce, Reuse, Recycle, Recover principles are the Repair and Remanufacture ones for the companies with five Rs, while for the most pioneering company is added to the adoption of Refuse, Repair and Remanufacture principles. The scores here are 29, 29, and 36.

Finally, Fig. 6 presents the revenues of the companies that are classified to the four categories. The most pioneering company in CE practices disclosed the highest revenue during 2022 (€ 12.82 bn). All the companies with almost € 7 bn and more were classified as either pioneer, or lagging CE forest companies. On the other hand, the infant and innovative companies disclosed a revenue of less than € 4 bn with a minimum of € 0.05 bn.

This seemingly positive relationship is also confirmed by applying the Spearman's rank correlation test. It was applied to the pair variables of 2022 revenues and TCS_GRI. It was estimated to rho = 0.745 with $p < 0.001$, indicating a statistically significant positive relationship between the two aforementioned variables, meaning that CE practices and revenues are positively related.

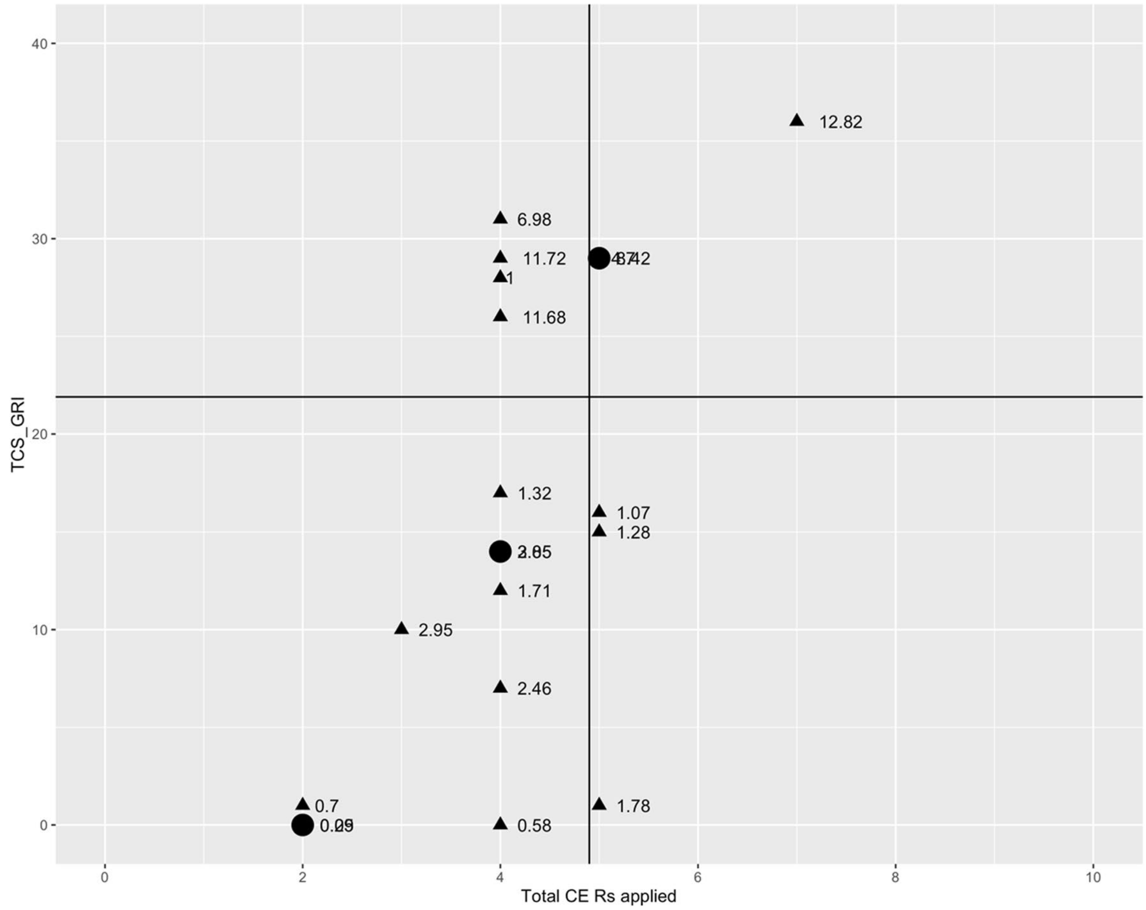

Fig. 6 Companies classification according to their revenue and circularity performance

5 Discussion

The findings show many contributions on both theoretical and empirical level of relative literature. At a theoretical level, this paper contributes to the field of CE and sustainable development by developing a technique for mining data from sustainability reports and offering real data on the behavior of companies in the forest sector regarding CE. The mining data technique was based on the experience of the field of environmental reporting which is more advanced in these techniques [37]. The proposed methodology is extremely promising as it responds to researchers' requests for relevant information [14]. The transfer of this know-how assists in examining behavioral issues of forest sector that until now have only been examined with the assistance of questionnaire-based surveys that could contain biased information that are difficult to detect and influenced by overestimating or underestimating research findings [46]. This agrees with the research of [47] who argue that more reliable information is needed to record the trends of forest enterprises in bioeconomy issues. Quantitative information requirements are high and necessary for reliable findings.

The suggested scoring system also provides contribution to the development of a cooperative, reliable and useful for every forest companies system regarding CE issues. The proposed methodology helps to overcome the limits set by the research of [48] in which measurement techniques are limited resulting in biased measurements. The lack of evaluation systems of circularity performance of forest companies is addressed by the suggested methodology. Ensuring the uniformity and comparability of information is achieved with the help of GRI indicators, offering certain categories of information that should be evaluated in order to measure the cyclicality of companies. This is confirmed by [49] that point out that more reliable and transparent information is needed arisen from corporate sustainability reporting. The suggested technique contributes, also, to the general literature of the measuring of the cyclicality of companies, which recently has incurred a relevant development [50, 51]. The assessment of different components of sustainability, such as the circular economy, offers important lessons in the field of analyzing the quality of non-financial information and calculating the degree of risk [52, 53].

Another important theoretical contribution is made on typologies of forest companies behavior towards CE. So far, most studies have focused on examining experts' suggestions about CE strategies for deploying circular economy strategies for forest products [54] and cluster analysis to categorize groups of forest companies in accordance with their perceived performance in CE [55]. Some of the findings is explained from [56] study which shows that the behavior of forest firms is affected from institutional and market-driven incentives. The advantage of the proposed typology lies in the reveal of the existing behavior, rather than the eventual intention of forest companies on CE issues. It is a technique intended for capturing the result and not the intention as seen today in most of the existing research studies. An equally significant contribution to the relevant literature is the four categories of behavior that the typology concludes since it emphasizes pioneers, innovators, lagging and infant. These categories provide for the first time a classification of behaviors that is useful to both theorists and practitioners for the examination of forest enterprises. The proposed typology of forest companies' behaviors overcomes the fragmented literature on the motivations of forest companies to switch to the bioeconomy [24, 57]. Although it agrees with various studies on some types of the behaviors [14, 58], it, nevertheless, identifies more alternative motivations that interpret this shift of forest enterprises to the bioeconomy as pioneers and innovators.

This research, furthermore, contributes to empirical research by analyzing real data from high revenue forest companies. Despite the small number of the sample, it is extremely encouraging that the companies in the sector have entered either to a greater or lesser extent into the circular economy sector. This agrees with the research findings presented in [59], which demonstrate that the relatively newly founded forest companies may lack the experience necessary to introduce topics related to bioeconomy. The findings suggest an awareness among companies of CE practices. Nevertheless, there exists an opportunity for companies to enhance their CE initiatives through the implementation of supplementary measures, since most of the companies were found to be infant in terms of CE practices. This was related to lower revenues compared to higher revenue companies, which showed a better performance on CE issues. This is confirmed by [14] who emphasizes resource efficiency as a critical factor influencing the adoption of sustainable bioeconomy practices by forest companies.

The research additionally showed that CE can be applied to all stages and activities of the value chain and not only to waste management. This is also proven by the GRI indicators. In other words, it is observed that circularity practices can be applied, apart from the waste management sector ("GRI 306: Waste 2020") and in the sectors of materials, water, effluents and GHG emissions. Furthermore, CE practices can be applied in areas of the assessment of the environmental behavior of suppliers and the health and safety of customers, highlighting the responsibility of all those involved in the value chains activities and giving social dimensions to the implementation of the circular economy. It is also observed that circularity is linked to areas of economic performance and indirect economic impacts ("GRI 201: Economic Performance 2016" and "GRI 203: Indirect Economic Impacts 2016" respectively), thus giving economic dimensions to the adoption circularity strategies.

6 Conclusions

The present research studied the CE practices of the forest sector through their disclosure in the annual non-financial reporting. It is one of the first papers which used the sustainability reports of the forest companies to derive knowledge about the contribution of the sector to circular economy. By doing that, a theoretical contribution has been made by the provision of a scoring system to mine information about the CE practices of the companies, and produce a typology of their contribution to CE. Empirical data, also, showed that most of the sample companies can be considered as infants at the CE practices, representing a moderate adoption of CE principles. Some forest companies are classified as innovative in CE practices which follow more than the four most used principles (Reduce, Reuse, Recycle, and Recover), and three of the sampled firms are classified as the Pioneer Circular Forest Companies being the leaders in CE practices. Finally, statistical analysis indicated positive relationship between CE practices and revenues of the forest companies.

However, like any other research study, there are some limitations that should be analyzed in order to ensure the reliability of the findings and create the appropriate conditions for future research. An important limitation is the way in which the thresholds are defined in the Typology Matrix, such as the five CE principles and more than half of the GRI indicators. These thresholds were based on the approach of rewarding "best in class" companies, which is a common practice in these measurement techniques [60]. However, it lacks empirical and research documentation, a fact that cannot ensure the avoidance problems such as the rebound effect, a fact that forms the conditions for future research that may clarify, depending on the company's activity, which principles, how many principles, which indicators and how many indicators should be satisfied in order to be classified in the suggested Typology Matrix.

A second limitation is that the sample selection includes only large companies that publish sustainability reports which excludes the study of SMEs. This approach may negatively affect the generality of findings. In the future, it would be possible to investigate other types of forest companies with lower revenues, from different countries and continents, to examine the effects of the institutional regime on CE behavior. Another limitation or rather a conclusion that requires further investigation is whether the implementation of the CE increases the revenue of the sampled forest companies or whether the forest companies with high revenue have the financial capital to invest in more CE principles. It would be an excellent area of future research to investigate intermediate variables such as intellectual capital, innovations and knowledge creativity induced by the application of CE principles.

Author contributions D.P., K.P., I.N. wrote part of the main text. D.P. collected the data, I.N. developed the framework, K.P. made the calculations and the statistical analysis. All authors read and approved the final version of the paper.

Data availability Data are available upon request to corresponding author.

Code availability Not applicable.

Declarations

Competing interests The third author, Ioannis E. Nikolaou, is Guest Editor at the Special Issue where the paper is submitted.

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