CIRCuSIV: a circularity and sustainability assessment tool for companies manufacturing industrial vehicles

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ORIGINAL PAPER

CIRCuS-IV: a circularity and sustainability assessment tool for companies manufacturing industrial vehicles

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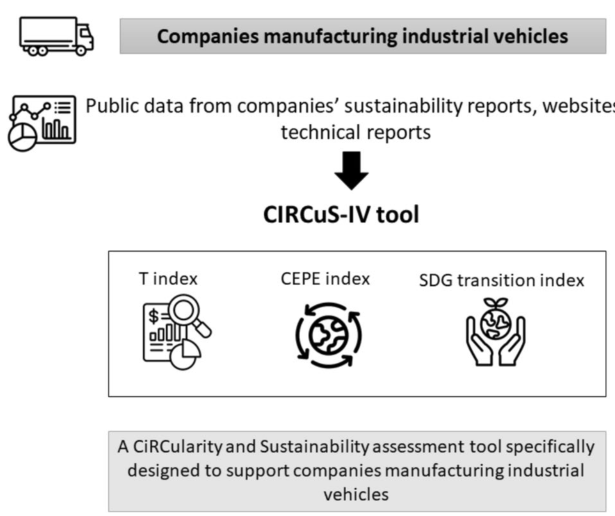
Abstract

Sustainability reports are essential for companies to publicly disclose their efforts towards the achievement of Circular Economy principles and of the Sustainable Development Goals (SDGs). This work presents CIRCuS-IV, a circularity and sustainability assessment tool specifically designed to support companies manufacturing industrial vehicles. The tool is fed with publicly available data retrieved from sustainability reports, companies' websites, technical reports, etc. The assessment is semi-quantitative and includes environmental, economic and social performance indicators. The tool involves 2 levels of evaluation (of current situation of the company and of its transition towards sustainability) defined by 2 macro-areas (actions and strategies) and 11 related aspects, 23 categories and 63 sub-categories. The assessment considered two boundaries: organization and products. The assessment score is delivered through three newly designed performance indicators: T index—evaluating the company's transparency based on the amount of publicly available data and information; CEPE index, a composite indicator evaluating the circularity and sustainability of the company; and the SDG transition index. CIRCuS-IV tool was calibrated on 3 competing companies, e.g. CNH Industrial, Daimler and Volvo Group. The obtained results showed that CNH Industrial and Daimler are more transparent and proactive towards circular and sustainable business models compared to Volvo Group. CIRCuS-IV supports companies manufacturing industrial vehicles by comparing their circularity and sustainability efforts; however, its reliance on public data limits completeness and standardization. Therefore, enhancing the scoring system with quantitative, company-specific data and third-party validation would improve accuracy. Future research should expand the tool to other industrial sectors for wider applications.

Graphical Abstract



Keywords Assessment · Circular business model · Circular economy · Sustainability · Vehicles

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Introduction

Acting towards circular economy (CE) and sustainability to transition into new models of economy is one of the crucial challenges of this era. The European Green Deal (European Commission 2019) and the new Circular Economy Action Plan (European Commission 2020) are strategic initiatives of the European Commission aimed to promote Europe's transition into carbon neutrality by 2050. Among the many definitions of CE (Kirchherr et al. 2017), the Ellen MacArthur Foundation provides one of the most used: "A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end of life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business model" (Ellen MacArthur Foundation 2013). Nowadays, companies play a fundamental role in our society, but they are also drivers of environmental problems (Bjørnbet et al. 2021). CE can be considered an "umbrella concept" (Castro et al. 2022) since it allows to shift towards more sustainable practices, involving the environmental, social and economic dimensions. For a manufacturing company becoming circular and sustainable involves keeping resources and products as long as possible, reducing waste, creating a sustainable, competitive and resource efficient economy, businesses, social and jobs opportunities (European Commission 2015), implementing sustainability practices at the core of strategy plans and priorities, and setting goals aligned with the Sustainable Development Goals (SDGs) (GRI et al. 2015). Sustainability reports are public documents required by the Corporate Sustainability Reporting Directive 2022/2464/EU (European Parliament and of the Council 2022) and disclosed by companies to communicate their efforts towards the achievement of the 17 SDGs. Sustainability reports declare transparently the company's priorities and strategies within the environmental, social and economic dimensions, leading to internal and external benefits (GRI 2016). Hence, sustainability reports are crucial to support the transition towards the Circular Economy practices within industrial sectors (Ibáñez-Forés et al. 2022).

Currently, various methodologies are applied to estimate sustainability within the industrial world. Environmental, Social and Governance (ESG) ratings (European Commission 2024) assess the sustainability of a company based on environmental, social, and governance risks and impacts. ESG guide the investors in sustainable strategies and help companies to manage risks, seize opportunities, and benchmark performance. In addition to ESG reports prepared by companies, third-party organizations gather ESG-related data to create company-specific ratings, offering to the investors a unified metric to evaluate and compare the ESG performance of companies over time (Fikru et al. 2024). Notable ESG rating providers include Sustainalytics, Bloomberg, and Refinitiv (Fikru et al. 2024). Concerning standards, the Global Reporting Initiative (GRI) is the most widely adopted framework worldwide for corporate sustainability reporting (Giannarakis et al. 2023). This international framework enables companies to present the environmental, social, and economic impacts in a clear and standardized mode (van Oorschot et al. 2024). Furthermore, the Sustainable Balanced Scorecard (SBSC) builds on the traditional Balanced Scorecard (BSC) by integrating environmental, social, and economic objectives, providing a comprehensive framework for aligning business strategies with sustainability goals, and supporting companies to evaluate their performance across all three dimensions of sustainability (Chehimi and Naro 2024; Fathi 2019).

A circularity assessment based on performance indicators can encourage companies to quantify and improve their circularity (Payer et al. 2024; Saidani et al. 2019), and efforts were devoted to assessing circularity in various sectors. Within existing literature, the available CE indicators are both quantitative and qualitative (Corona et al. 2019; Jerome et al. 2022; Kristensen and Mosgaard 2020; Saidani et al. 2019; Vinante et al. 2021), and they can be designed at micro- (products, companies, consumers), meso- (eco-industrial parks) and macro-levels (city, region, nation and beyond) (Kirchherr et al. 2017). CE indicators have been developed across a wide variety of sectors, such as building and construction (Khadim et al. 2023; Pilipenets et al. 2024), mining (Ibañez et al. 2023), automotive (Matos et al. 2023), maritime (Faut et al. 2023), wastewater treatment (Preisner et al. 2022), chemical (Kusumo et al. 2022), fashion (Galatti and Baruque-Ramos 2022), education (Valls-Val et al. 2024), agri-food (Poponi et al. 2022; Silvestri et al. 2022), healthcare (Matschewsky et al. 2024) and energy (Serrano-Arévalo et al. 2024). The above-mentioned indicators are based on different approaches and contexts, and a reference method or set of indicators is necessary to provide guidance to the companies (Vinante et al. 2021). Specifically considering circularity assessment at micro-level, it may involve a product or a company.

Moreover, the adoption of circularity indicators depends on company size and business models. In particular, small and medium-sized enterprises (SMEs), which account for a large portion of manufacturing firms, may often encounter specific challenges when adopting such tools. In this context, Sundin et al. (2015) developed a tailored set of indicators to support the development of Product-Service System solutions for SMEs, emphasizing the importance of keeping the number of indicators limited to reduce additional workload, and highlighting that these indicators should serve as starting points helping companies select the most relevant measures to effectively monitor their progress towards environmental sustainability.

Amongst the existing literature on CE indicators (Table 1), some studies performed a critical and systematic review of existing CE index (Calzolari et al. 2022; De Pascale et al. 2021; Elia et al. 2017; Moraga et al. 2019; Pacurariu et al. 2021); Saidani et al. (2017) and Linder et al. (2017) reviewed the existing CE assessment tools; Rincón-Moreno et al. (2021) adapted existing indicators to measure circularity of companies; other studies (Azevedo et al. 2017; García-Sánchez et al. 2021; Kayal et al. 2019; Smol et al. 2017; Pacurariu et al. 2021; Linder et al. 2017) proposed new indices to assess circularity at different levels.

The recent ISO standard for Circular Economy ISO 59020:2024 identified comprehensive frameworks for the assessment of companies through a set of indicators designed to provide standardized metrics, enhancing consistency and comparability in CE practices across various sectors. The European Commission defined ten CE indicators across four areas: production and consumption, waste management, secondary raw materials, and competitiveness and innovation (European Commission 2018). In production and consumption, the focus is on waste reduction and efficient material use; waste management indicators monitor recycling rates, especially for municipal and packaging waste; secondary raw materials indicators track the use of recycled materials to replace raw resources; finally, competitiveness and innovation indicators assess job creation, investment, and innovation in circular economy sectors (European Commission 2018). The Ellen MacArthur Foundation developed two relevant tools: the framework Circulytics (Ellen MacArthur Foundation 2021), designed to measure the circularity performances of companies going beyond the material and product flows, offering qualitative and quantitative insights and evaluating the overall performance of a company. Participation is voluntary, scores are confidential unless disclosed by the company, with anonymous data used for industry benchmarks. Similarly, the CE Toolkit (CE Toolkit 2013) quantifies the circularity of a product. Inventories of existing indicators were released by the Organization for Economic Co-operation and Development (OECD 2020), by the Circular Economy Policy Research Centre (Vercalsteren et al. 2017), and a system of quantitative indicators for companies was proposed by the World Business Council for Sustainable Development (WBCSD 2021).

Based on the performed literature review, the main knowledge gap in the topic of circularity and sustainability assessment of companies is the lack of reference frameworks, metrics and indicators designed for specific industrial sectors. For many companies, sustainability reporting aligns to internationally recognized standards, such as GRI standards (GRI 2024) and the Sustainability Accounting Standards Board (SASB) (SASB 2024). However, GRI standards require only that companies disclose information on a general level without sector-specific or standardized metrics, which limits specificity and comparison. Furthermore, both GRI and SASB standards focus on voluntary disclosures, thus allowing companies to significant preference over what they report, leading to potential variability and inconsistencies in data quality. SASB standards are industry-specific, but they may not cover broader environmental, social, and governance issues or match global frameworks, making them less useful for some stakeholders and regions. Moreover, data and information disclosed by the companies in the sustainability reports are often not validated nor certified by any third party. Data are often provided as aggregated and/or qualitative, making difficult a quantitative assessment of a company and a critical comparison within a specific industrial sector.

This study aims to investigate if the circularity and sustainability assessment of a company can be based on the data publicly disclosed in sustainability reports, technical reports, companies' websites, etc. This study specifically considers the industrial vehicles sector, as circularity and sustainability assessment can be a valuable tool for such companies to improve decision-making processes, enhance resource efficiency, reduce environmental impact, and align their operations with global sustainability goals. For this study, we consider industrial vehicles as all motorized machinery and equipment that fall outside the scope of the automotive sector, which typically includes road vehicles weighing less than 3.5 tonnes (Saidani et al. 2018). Specifically, industrial vehicles refer to both heavy duty vehicles, mainly trucks and buses with a gross vehicle weight rating above 3.5 tonnes; and non-road mobile machinery, which includes any mobile machine not intended for carrying passengers or goods on the road, typically used in sectors such as agriculture, construction, mining, and forestry (e.g. tractors, excavators) (Saidani et al. 2018). The main goal of this study is to develop an assessment tool, named CIRCuS-IV, based on semi-quantitative and qualitative indicators to support companies manufacturing industrial vehicles in the transition towards circular economy and sustainability. CIRCuS-IV includes environmental, economic and social performance indicators defined through a sequential evaluation considering 2 macro-areas (actions and strategies) and 11 related aspects, 23 categories and 63 sub-categories. The assessment considers two levels: (i) the evaluation of the circularity and sustainability of the present situation of the company based on quantitative and qualitative information; and (ii) the estimation of the progress into the transition towards sustainability based on qualitative information. The scores of the 23 levels of assessment are calculated via newly proposed

Table 1 Overview of selected relevant literature on Circular Economy indicators

Reference	Type	Specific sector	Topic
Pilipenets et al. (2024)	RA	Construction	Proposal of a storage circularity indicator to address the issue of long-term waste stockpiling in circular economy models, enhancing sustainable waste management strategies
Valls-Val et al. (2024)	RA	Education	Development of a set of 82 tailored circular economy indicators, along with 41 improvement actions, to help universities to support and enhance their circularity
Matschewsky et al. (2024)	RA	Healthcare	Review of circular indicators to guide the design and procurement of plastic medical products, highlighting their potential to reduce environmental impact and drive the healthcare sector's transition to a circular economy
Serrano-Arévalo et al. (2024)	RA	Energy	Multi-objective optimization model incorporating Circular Economy indicators to balance costs, CO2 emissions, and resource depletion in power system planning, demonstrated through a case study in Mexico
Khadim et al. (2023)	RA	Construction	Development of the Whole-Building Circularity Indicator (WBCI), a comprehensive tool for measuring building circularity, addressing gaps in existing frameworks, and validating it through a case study of an Italian residential building
Ibañez et al. (2023)	RA	Mining	Proposal of a circularity indicator for mining, enabling comparisons of operations over time by assessing production, CO2 emissions, water use, and energy consumption
Matos et al. (2023)	RA	Automotive	Identification of 23 circularity micro-indicators for automotive plastics, highlighting opportunities for sustainable materials and end-of-life recovery while addressing industry practices that limit circular economy adoption
Faut et al. (2023)	RA	General	Development of a set of circular economy indicators for ports, aiming to help port authorities and stakeholders track and manage the transition to a circular economy, based on a comprehensive multimethod research approach
Jerome et al. (2022)	REV	General	Analysis of resource-based indicators for circular economy assessment, testing their effectiveness and comparing them to life cycle assessment
Preisner et al. (2022)	REV	wastewater	Review of existing indicators for resource recovery in the wastewater sector, aiming to improve the tracking of circular economy practices, and proposal of a new circularity indicator for wastewater treatment plants to address emerging challenges
Kusumo et al. (2022)	RA	Chemical	Development of a framework to evaluate circular economy indicators and implementation in biological systems, highlighting interconnected mechanisms and a three-step assessment approach
Galatti and Baruque-Ramos (2022)	RA	Fashion	Development of 40 social indicators to evaluate the Brazilian textile industry's role in promoting social innovation within a circular economy
Poponi et al. (2022)	RA	Agri-food	Development of a dashboard with 102 indicators across environmental, economic, and social dimensions to guide the agri-food sector's transition to a circular economy, highlighting gaps in current indicators
Silvestri et al. (2022)	RA	Agri-food	The article reviews energy-related indicators in the agri-food sector, highlighting key activities like machinery use and transport, the impact of fuel sources, and clean energy usage, while identifying barriers like technological gaps and inefficient subsidies
Calzolari et al. (2022)	RA	General	Review of tools and indicators for Circular Supply Chains, highlighting a focus on environmental and economic impacts while overlooking social aspects
Vinante et al. (2021)	REV	General	Review of 365 CE metrics, organizing them into a circular Value Chain framework, and highlighting their broad applicability for firm-level CE assessments while addressing the fragmentation of current assessment models
De Pascale et al. (2021)	RA	General	Review of 61 circular economy indicators from 137 studies (2000–2019), classifying them by spatial scale of sustainability and 3R principles
Pacurariu et al. (2021)	REV	General	Evaluation of the current Circular Economy monitoring indicators and proposal of a new indicator
Rincón-Moreno et al. (2021)	RA	General	Proposal of a set of circular economy indicators, demonstrating their applicability at the micro-level and recommending their use across sectors to aid the transition to a circular economy
(García-Sánchez et al. 2021)	RA	General	Development of a two-step Circular Economy Business Index based on 17 environmental practices, analysing data from over 26,000 companies across 49 countries and 10 sectors to assess global progress in circular transformation
Kristensen and Mosgaard (2020)	REV	General	Review of 30 micro-level circular economy indicators, highlighting their focus on end-of-life management and economic aspects

Table 1 (continued)

Reference	Type	Specific sector	Topic
Corona et al. (2019)	REV	General	Analysis of circularity metrics for products and services, evaluating their alignment with sustainability and offering recommendations to avoid unintended impact
Saidani et al. (2019)	REV	General	Review of 55 circularity sets indicators (C-indicators), proposes a classification taxonomy based on factors such as implementation level and CE loops, and provides a tool to help select appropriate indicators for industry use
Moraga et al. (2019)	RA	General	Proposal of a framework to classify Circular Economy indicators based on their focus (e.g. material preservation or product functions) and measurement scope
Kayal et al. (2019)	RA	Wastewater	Proposal of the Circonomics Index to evaluate the circularity of wastewater treatment, emphasizing efficiency in reuse and recycling
Kirchherr et al. (2017)	REV	General	Analysis of 114 circular economy definitions, highlighting a focus on reduce, reuse, and recycle, with minimal focus on systemic change or social equity
Elia et al. (2017)	RA	General	Proposal of a framework for assessing circular economy strategies and evaluates existing environmental assessment methods for measuring circularity
Saidani et al. (2017)	RA	General	Review of three approaches to measuring product circularity performance, highlighting their limitations and providing recommendations for developing more comprehensive tools and guidelines to support circular economy practices in industry
Linder et al. (2017)	REV	General	Proposal of a circularity metric based on recirculated economic value, aiming to improve product-level circularity measurement and suggesting further refinement for broader use
Azevedo et al. (2017)	RA	Manufacturing	Proposal of a Sustainable Circular Index (SCI) to help manufacturing companies assess and improve their sustainability and circularity performance through a five-phase framework
Smol et al. (2017)	REV	General	Proposal of a set of circular economy indicators based on eco-innovation factors to assess regional CE progress, focusing on inputs, activities, outputs, resource efficiency, and socio-economic outcomes

Each reference is classified by type (RA: research article, REV: review article), specific sector (categorized as “general” if any sector is specified in the reference), and topic addressed

indexes. The tool was calibrated on 3 competing industrial vehicles manufacturing companies, e.g. CNH Industrial, Daimler and Volvo Group, whose performances were compared. This study aims to address the following research questions: 1. To what extent can the circularity and sustainability performance of companies manufacturing industrial vehicles be reliably evaluated using publicly available data? 2. What key indicators and metrics can be identified and integrated into an assessment framework, based on publicly available data, to effectively evaluate circularity and sustainability in the industrial vehicles sector?

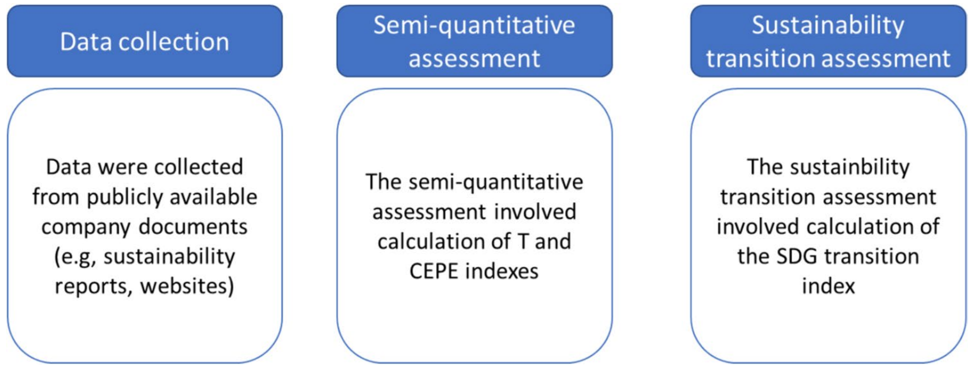
Methodology

Overview of the assessment tool

The developed tool contributes to both circularity and sustainability of companies manufacturing industrial vehicles. The tool was developed through a structured process combining literature review, analysis of existing methodologies, relevant standards and regulations related to circularity, sustainability, and alignment with the SDGs. Particular attention was focused to the specific needs of the industrial vehicle sector, examining the lack of suitable approaches for effectively measuring circularity and sustainability in this industry. For this reason, a key objective was to design a tool that could rely primarily on publicly available data, ensuring transparency, replicability, and broad applicability without requiring access to confidential company information.

Specifically, circularity is assessed considering resource conservation and products life extension, focusing on their environmental compatibility, recyclability and recoverability. Meanwhile, sustainability is evaluated encompassing the environmental, social, and economic dimensions. This includes not only corporate practices (e.g. sustainable policies, human rights, employee welfare) but also the sustainability performance of products, such as their environmental impact, energy efficiency, and long-term value creation. By addressing both circular and sustainable aspects, the tool enables a comprehensive assessment of a company’s overall contribution to sustainable development goals. Furthermore, sustainability is also assessed in terms of alignment with the SDGs; therefore, by addressing both circular and sustainable aspects, the tool enables a comprehensive assessment of a company’s overall contribution to sustainable development. The tool proposed in this study (Fig. 1) considers two levels and three newly designed indicators. A

Fig. 1 Concept of the present study



semi-quantitative assessment based on quantitative data and qualitative information describes the circular and sustainable actions and strategies implemented by the analysed company. This phase involves a sequential categorization of the data and information into macro-areas, aspects, categories and sub-categories. The sub-categories define the performance indicators integrated in the tool and the final score is based on two indicators: T index, estimating the company's transparency based on the amount of publicly available data and information, and CEPE index, a composite indicator evaluating the circularity and sustainability of the company. Then, a qualitative assessment of the transition into sustainability based on the goals declared by the companies was performed, with a final score calculated via the SDG transition index. The two levels of assessment were designed to be fed with publicly available data provided by sustainability reports, technical reports, websites, etc., disclosed by the companies or a third party. CIRCuS-IV involves two types of boundaries, e.g. organization (data and information are related the whole company) and products (data and information are related to the products). Within the organization boundary, the items accounted are reducing the quantity of resource inputs, waste and emissions and adopting measures to intensify and increase the use of materials and resources (Geissdoerfer et al. 2020). In products boundary, the assessment evaluates capturing the economic and the environmental embedded values of products, parts and materials through the long-life design, repairing, remanufacturing and recycling (Nußholz 2017).

Level 1: semi-quantitative circularity and sustainability assessment

The semi-quantitative assessment (Fig. 2) is organized into two macro-areas: "actions" and "strategies", identifying the related aspects and categories for the two boundaries "organization" and "products". While the actions involve both boundaries, the strategies are related to the organization. The sub-categories express the environmental, economic and social performance indicators.

The macro-area "actions" includes 4 different aspects, e.g. resource conservation, biodiversity, sustainable design criteria and end of life, 10 categories and 33 sub-categories (Table 2). Considering the boundary "organization", the macro-area "actions" encompasses the practices that an industrial vehicle manufacturing company should implement to shift towards circularity and sustainability, both at organization and products levels. Substantial environmental actions are limiting the use of fossil fuels and increasing the share of renewable resources, recovering and recycling water and waste, reducing emissions, hazardous waste and raw materials' consumption. Painting is a significant phase of vehicles manufacturing process, and it is directly related to the emissions of volatile organic compounds, harmful for the human health. Packaging waste is another important subject requiring mitigation actions, such as replacing disposable materials with reusable ones and increasing reuse and recycling rate. Biodiversity loss has dramatic consequences, and its prevention is essential for industries, which are required to include biodiversity protection into their core strategy plan, promoting projects and initiatives to preserve nature and wildlife.

As for the boundary "products", the macro-area "actions" evaluates their whole life cycle, from sustainable design criteria to end-of-life management. The design phase of products is crucial as it defines their performances during use and end of life. Key actions related to sustainable design are adopting recycled/remanufactured materials to reduce the use of primary resources, eliminating hazardous substances and choosing circular materials that can be further recycled, remanufactured and refurbished, and designing products to last as long as possible, avoiding the single use. Specifically considering the use phase of products, key actions for industrial vehicles manufacturing companies are reducing exhaust gases emissions, improving health and safety standards. Concerning the end of life of the products, the defined actions comprise recycling, remanufacturing and second life as alternatives.

The macro-area "Strategies" contains 7 aspects (policies, supply chain, expenditure and investments, certifications,

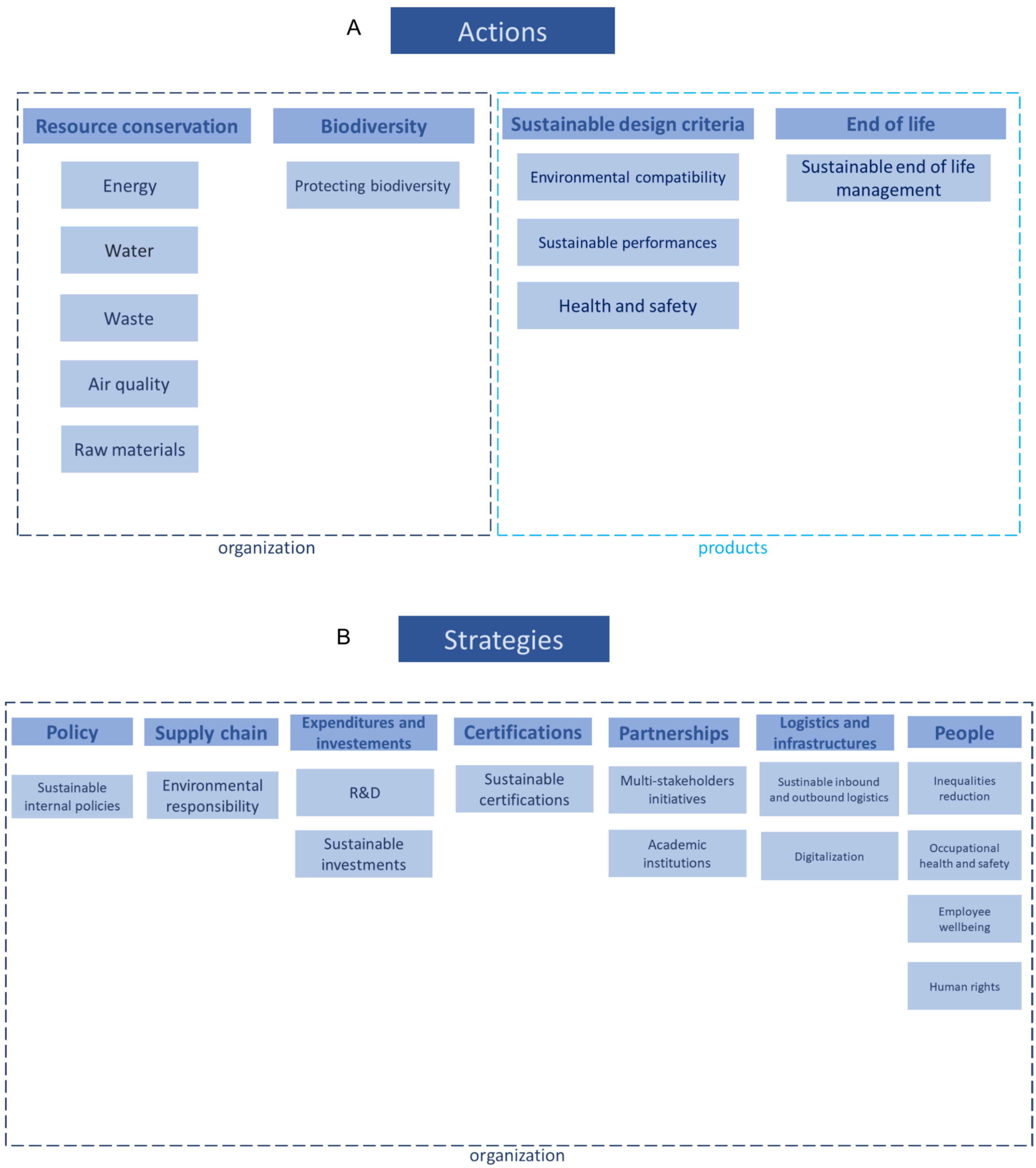


Fig. 2 Outline of level 1 of CIRCuS-IV tool—semi-quantitative circularity and sustainability assessment: macro-areas **A** Actions and **B** Strategies and associated aspects and categories

partnerships, logistics and infrastructures, and people), 13 categories and 30 sub-categories (Table 3). The boundary defined for Strategies is "organization". The significant items accounted within the macro-area Strategies are as follows. Policies are essential instruments for companies to achieve sustainability protecting the environment and the health and rights of the employees. The "supply chain" aspect assumes that CE principles should be integrated in

Table 2 Details of the aspects, categories and sub-categories defined for the macro-area "Actions" (*COD* chemical oxygen demand, *LCA* life cycle assessment, *VOC* volatile organic compounds)

Aspect	Boundary	Category	Sub-category
Resource conservation	Organization	Energy	Total energy consumption from renewable resources Electricity consumption from renewable resources Reduction of energy consumption over time
		Water	Water reuse/recycling Reduction of total water consumption over time Responsible wastewater management Sustainable water withdrawal Water quality discharge improvement (COD)
		Waste	Waste recovering/recycling Responsible waste management Responsible packaging waste management Hazardous waste recycling Reduction of hazardous waste production
		Air quality	Reduction of CO_2 emissions over time Reduction of significant emissions (NO_x, SO_x) Reduction/elimination of ozone depleting substances over time VOCs reduction for painting processes
		Raw materials	Reduction of raw materials consumption
Biodiversity		Protecting biodiversity	Biodiversity assessment Life on land protection (projects and initiatives) Volatile life protection (projects and initiatives) Marine life protection (projects and initiatives)
Sustainable design criteria	Products	Environmental compatibility	LCA performances Recyclability/Recoverability Elimination of critical substances Use of secondary raw materials
		Sustainable performances	Use of alternative fuels Use of alternative power systems Emissions reduction and efficiency improvement
		Health and safety	Improved safety standards Improved comfort standards
End of life		Sustainable end-of-life management	Remanufacturing Recovering/Recycling

the company's supply chain management to reduce impacts and achieve SDGs targets. The choice of suppliers should be aligned with sustainability principles and practices (e.g. ownership of environmental certifications). Furthermore, periodic assessments and monitoring are useful to identify risks and implement corrections in the supply chain management. "Expenditures and Investments" aspect represents one of the strategic drivers for companies in terms of circular and sustainable productivity, economic growth and job creation (GRI et al. 2015). Industrial vehicles manufacturing companies pursue the achievement of circularity and sustainability through activities related to research and development (R&D), environmental protection and the development of circular innovative products (e.g. vehicles with increased efficiency, less exhaust gases emissions, recyclable materials). The aspect "Certifications" includes "sustainable certifications" category, with the associated sub-categories referring to the specific certifications (Table 3) as EMAS, ISO 14001, ISO 50001, OHSAS 18001/ISO 45001. The certifications are released by third-party, and the companies adhere voluntarily complying with specific standards of environmental management systems (EMAS and ISO 14001), energy management systems (ISO 50001) and occupational health and safety management systems (OHSAS 18001/ISO 45001). Therefore, these certifications represent for the companies an opportunity to shift towards more sustainable management systems, also improving credibility and transparency internally (towards employees) and externally (towards customers, suppliers and stakeholders).

"Partnerships" aspect considers the collaborations between the investigated company and third parties (e.g. other companies, academic institutions, policy makers, etc.) to develop new solutions, achieve common goals and overcome shared challenges (GRI et al. 2015). "Logistics and infrastructures" aspect represents the core of any company's activities through the supply chain (analysed in a separate aspect), manufacturing processes, transportation of goods and finished products to customers. The adoption

Table 3 Details of the aspects, categories and sub-categories defined for the macro-area "Strategies"

Aspects	Boundary	Categories	Sub-categories
Policies	Organization	Sustainable internal policies	Environmental policy Health and safety policy Energy policy Human rights policy
Supply chain		Environmental responsibility	Suppliers' compliance to sustainability Suppliers' sustainability assessment and monitoring
Expenditures and investments		Research and Development	Research and development expenditures
		Sustainable investments	Environmental protection expenditures/investments Sustainable products investments
Certifications		Sustainable certifications	Environmental: EMAS Environmental: ISO 14001 Energy: ISO 50001 Health and Safety: OHSAS 18001/ISO 45001 Other certifications/programs
Partnerships		Multi-stakeholders' initiatives	Promotion of sustainable organization Promotion of sustainable products
		Academic institutions	Academic institution partnerships
Logistics and infrastructures		Sustainable inbound and outbound logistics	Environmental impact reduction Transport emissions reduction
		Digitalization	Efficiency improvement
People		Inequalities reduction	Employees gender equality Gender inclusion and racism
		Occupational health and safety	Employees benefits Risk management Training programs
		Employees wellbeing	Satisfaction Surveys
		Human rights	Initiatives Child labour Forced labour Harassment

of sustainable practices in logistics and infrastructures can support the transition towards a circular business model, specifically through environmental impacts' reductions in inbound and outbound logistics and through digitalization. "People" aspect considers the workforce of the companies, i.e. their most significant resource. Personnel wellbeing and occupational health and safety programs, respect of human rights by reducing all forms of gender and race inequalities, forbidding all forms of forced labour, child labour and harassment are all sub-categories related to "people" aspect.

After all required data and information are enclosed into the tables of CIRCuS-IV tool (Supplementary material—S2), an automatic calculation of the circularity and sustainability performances of the company happens (Supplementary material—S4). Two newly designed indicators contribute to the circularity and sustainability total score: the T index, evaluating the transparency of available information, and the CEPE index, appraising the circularity and the sustainability of the company. CEPE index is made of 4 inputs: Cycling index, Protecting Index, Extending Index and Enabling Index. Details about T and CEPE indexes are in the following.

T index varies between 0 (minimum score) and 59 (maximum score). It highlights the importance of the presence of public information, quantitative and qualitative, within each sub-category. The T index is calculated (Fig. 3) based on:

- A score between 0 and 1 is assigned for each sub-category (Sheet S4-Table P1). The only exception is the "Certifications" aspect, involving a score between 0 and 1 assigned to the entire category.
- Score 0 was assigned if public information regarding a specific sub-category is not available.
- For sub-categories requiring quantitative data (28 out of 63), score 1 is assigned if quantitative data are available, while if public qualitative information is provided, a score of 0.5 is assigned. The highest score ascribed to quantitative data highlights the importance to publicly "give numbers" to quantify and tangibly demonstrate the company's achievements (for example, if a company reports that electricity was provided by renewable

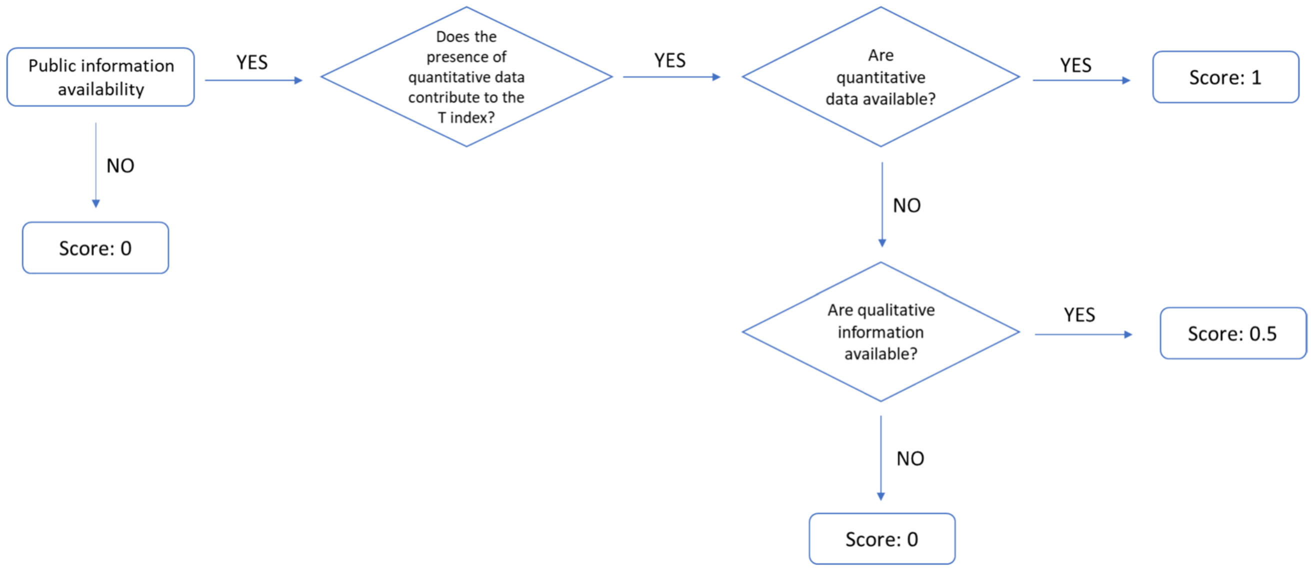


Fig. 3 Outline of the calculation of the T index

resources, it is important to quantify this share compared to the total electric energy use).

- For sub-categories not requiring quantitative information (such as the sub-categories associated with "Biodiversity" aspect), score 1 is assigned if qualitative information is provided.

The total numerical score and the alphabetical grade of the T index are automatically calculated by the tool (Supplementary material-sheet S4, Table P4).

CEPE is a composite index made of 4 inputs (Fig. 4): Cycling index, Extending index, Protecting index and Enabling index. The Cycling index was defined according to the strategies for circular business models reported by Geissdoerfer et al. (2020) and according to the circular business models described by Lacy et al. (2020). The Cycling index measures the circular inputs and resource recovery within the organization. Specifically, it refers to the replacement of the primary raw materials and resources with circular solutions, such as the adoption of renewable energy sources (Lacy et al. 2020), and reuse, refurbishment, recycling and remanufacturing practices (Geissdoerfer et al. 2020). The Extending index was based on the strategies for circular business models reported by Geissdoerfer et al. (2020) and the circular business models described by Lacy et al. (2020). The Extending index refers to the "Product use extension" (Lacy et al. 2020), e.g. the products' use phase is extended through circular design, maintenance, repairing, reconditioning and upgrading (Geissdoerfer et al. 2020). The Protecting index accounts the actions implemented by the company to protect the environment and human health, and it was designed according to the "Protecting our planet and health" indicator defined by Eurostat to monitor the achievement of the European Green Deal objectives (Eurostat 2022). The Enabling index refers to the strategies integrated into the company plan to promote the transition towards sustainability, and it was based on the "Enabling a green and just transition" indicator defined by Eurostat to monitor the achievement of the European Green Deal objectives (Eurostat 2022).

The above-described 4 inputs contribute differently to the CEPE index, as they refer individually to specific sub-categories receiving a score between 0 and 1. In details, score 0 is assigned if the action or strategy defined by the sub-category is not implemented by the company; score 1 is assigned if the action or strategy defined by the sub-category is implemented by the company. The CEPE index is calculated through a weighted average considering the number of sub-categories contributing to each input (Supplementary material-Sheet S3, Table P8) and rescaling the score in the range 0–100. The total numerical score of the CEPE index is automatically calculated by the tool (Supplementary material-sheet S4, Table P6).

Based on the values of the T index and of the CEPE index, different performance intervals were defined, e.g. grade A (51–59), grade B (41–50) and grade F (0–10) for T index; grade A (91–100), grade B (81–90) and grade F (0–5) for the CEPE index.

Level 2: qualitative assessment of sustainability transition

The second level of CIRCuS-IV tool (Fig. 5) evaluates the industrial vehicles manufacturing companies' transition towards sustainability based on qualitative information. Measurable short and long-term goals aligned with the 17 SDGs should be at the core of strategic plan and priorities of companies that aim to shift towards sustainability. The goals declared by the companies should include all areas, from manufacturing processes to products, logistics, investments and expenditures and workers. For this reason, the macro-area "Targets" was integrated in the tool to evaluate the goals declared by the company related to the 17 SDGs within a period between 2023 and 2050 (Supplementary material-sheet S3) across the two boundaries "organization" and "products".

A specific section allows to provide any qualitative information for each declared goal, e.g. the related SDG, the time interval (from 2023 to 2050) and the boundary (organization or product) The scoring system implemented on the second level of the tool is based on the presence/absence of targets related to specific SDGs via the "SDGs transition index" was formulated and it varies between 0 (minimum score) and 17 (maximum score):

- Score 1 was assigned for each SDG including related targets.
- Score 0 was assigned to each SDG not including related targets.
- If a specific SDG includes multiple targets, score 1 is assigned, i.e. it is considered the presence of targets, not the quantity.

At the end, the total numerical score of the SDG transition index is automatically calculated by the scoring tool (Supplementary material-sheet S4, Table P7). Based on the values of the SDG index, different performance intervals were defined, e.g. grade A (15–17), grade B (12–14) and grade F (0–2).

Calibration of the tool

CNH Industrial, Daimler and Volvo Group were engaged as case studies to calibrate CIRCuS-IV. The sources of data and information were the 2020 Sustainability Reports (CNH Industrial 2020; Daimler 2020; Volvo Group 2020) and technical reports available on the companies' websites. As concern the calibration, the analysis of the sustainability reports was crucial to refine both levels of the tool. In details, in level 1 the calibration assisted the design subcategories specific for the industrial vehicles manufacturing sector, such as the ones related to packaging, emissions from painting, lifecycle assessment performances, use of alternative fuels and power systems. In level 2, the correspondence among the declared goals and the SDGs was improved.

Results and discussion

CIRCuS-IV tool is provided, together with complete guidelines for its implementation, in Supplementary materials (sheet S1-guidelines, sheet S2-semi-quantitative assessment tool, sheet S3-SDGs transition assessment tool). The tool, implemented on MS Office Excel, is organized in Tables, and it demands to complete the sequential procedure described in the following:

- For each sub-category, it is required to select (YES/NO) through a drop-down menu if public information is available.
- If public information is available, it is required to specify (YES/NO) through a drop-down menu the application of the activity specified in the sub-category.
- For some sub-categories (e.g. Total energy consumption from renewable resources; Electricity consumption from renewable resources; Hazardous waste recycling, etc.) it is required to insert quantitative data—if available, and qualitative information. For others (Biodiversity assessment; Elimination of critical substances; Improved safety standards, etc.), only a qualitative description is required.
- For each sub-category, it is required through a drop-down menu (multiple choices allowed) to specify the source of the data and information choosing among sustainability report, public document/report released by the company, public document/report released by a third party, website, other sources. For each source, it is required to specify the reference detail (e.g. page of report, link to website, etc.).
- In the last two columns, it is required to specify the SDGs associated with the sub-category, and a "notes" section is available to include any additional information.

Calibration of level 1: semi-quantitative circularity and sustainability assessment

The results of the calibration of the level 1 of the CIRCuS-IV on the case-study companies CNH Industrial, Daimler and Volvo Group (Supplementary materials, sheets S5, S7 and S9) were as follows. Concerning the T index (Fig. 6A), CNH Industrial obtained the highest score (56/59), followed by Daimler (54/59) and Volvo Group (42.5/59). These results highlight the difference between the availability and the quality of public information for the three companies: CNH Industrial and Daimler 2020 Sustainability reports are the most complete, in fact they describe in detail the companies' activities and initiatives

Table 4 SDGs covering by the future targets of CNH Industrial, Daimler and Volvo Group

SDG	CNH Industrial	Daimler	Volvo Group
1.No poverty			
2.Zero hunger			
3.Good health and well being	✓		
4.Quality education			
5.Gender equality	✓	✓	✓
6.Clean water and sanitation		✓	
7.Affordable clean energy	✓	✓	✓
8.Decent work and economic growth	✓	✓	✓
9.Industry, innovation and infrastructure			✓
10.Reduced inequalities		✓	
11.Sustainable cities and communities			
12.Responsible consumption and production	✓	✓	✓
13.Climate action	✓	✓	✓
14.Life below water			
15.Life on land			
16.Peace, justice and strong institutions			
17.Parterships for the goals			

Fig. 4 Outline of the calculation of CEPE index

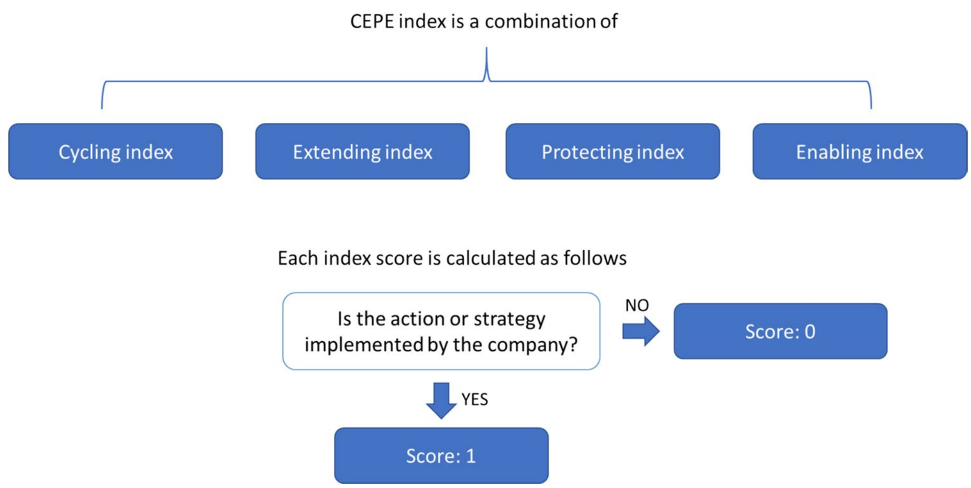
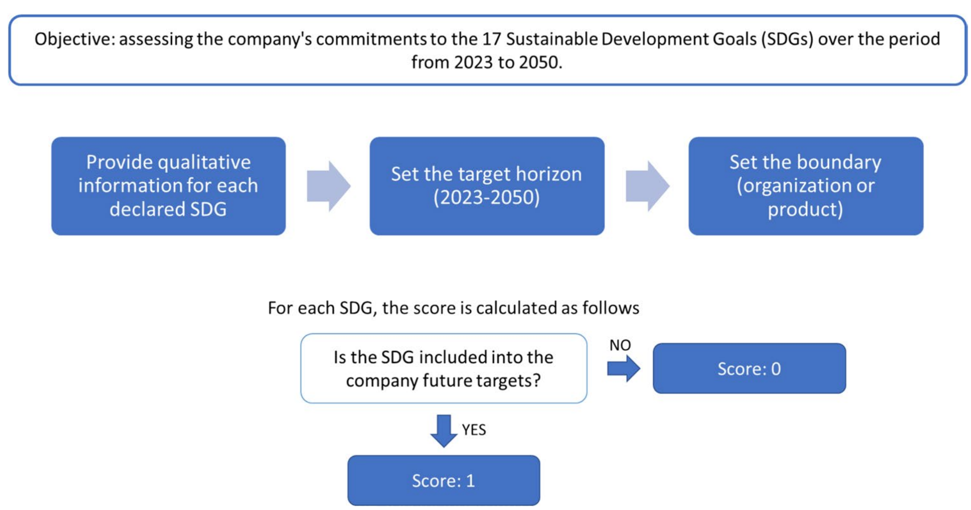


Fig. 5 Outline of level 2 of the CIRCuS-IV tool—sustainability transition assessment

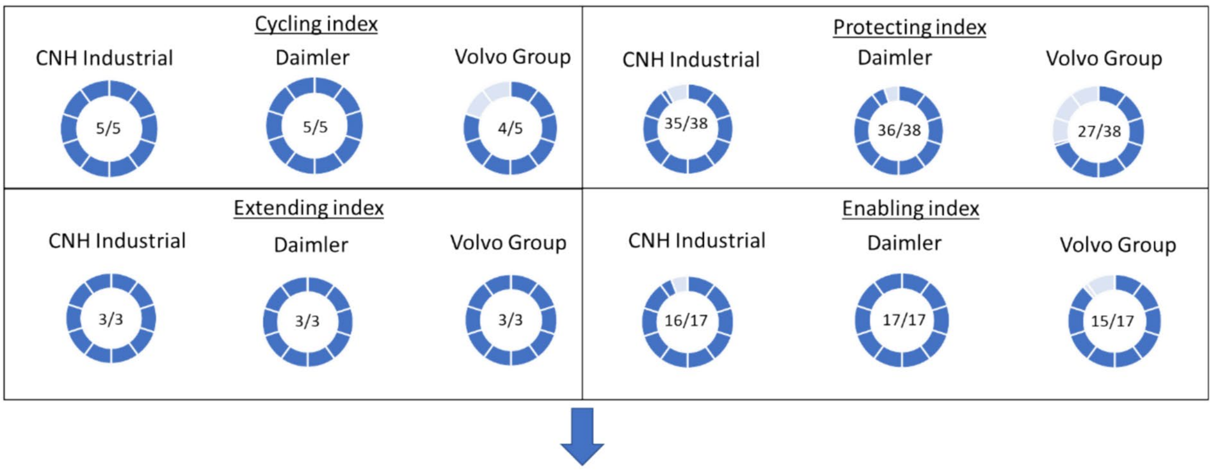


A

T index

Company	Score	Grade
CNH Industrial	56	A
Daimler	54	A
Volvo Group	42.5	B

B



CEPE index

Company	Score	Grade
CNH Industrial	93.7	A
Daimler	96.8	A
Volvo Group	77.86	B

Fig. 6 Calculation of the quantitative indicators in level 1 of CIRCuS-IV for the three case-study companies: **A** T index and **B** Cycling index, Extending index, Protecting Index, Enabling Index and CEPE index

relative to their sustainability performances and their transition towards the SDGs, giving also numbers and not only qualitative information; Volvo Group provides for the 2020 Annual and Sustainability report and, probably, due to this coupling of reports, the available information is more concise. Thus, other sources were used to feed the tool, such as websites and public documents. However, information about some specific analysed sub-categories were not available. Therefore, CNH Industrial and Daimler resulted more transparent in terms of information availability (grade A) than Volvo Group (grade B).

As regard the CEPE index (Fig. 6B), CNH Industrial and Daimler reached the maximum score, while Volvo Group obtained 4/5, due to the lack of information on hazardous waste recycling. All companies obtained the highest score for the Extending index, as they all adopt measures to extend as long as possible the life of their products by implementing sustainable design criteria, environmental, health and safety performances during the use phase and sustainable end-of-life management. Furthermore, the three case-study companies perform LCA evaluation on their products. Concerning the Protecting index, the highest score was calculated for Daimler (36/38) and CNH Industrial (35/38), while Volvo Group reached the lowest (27/38). For the latter, it is remarkable to notice the lack of public information on wastewater management and discharge, water withdrawal, biodiversity, use of ozone depleting substances, VOCs for the painting process, probably since Volvo Group presents the Annual and Sustainability report as a single document, while for CNH Industrial and Daimler was available the Sustainability report. Another sub-category that contributes to the Protecting index decrease for Volvo Group is the increase in hazardous waste production over the time, from 2018 to 2020. As regard Daimler, lack of information is related to water withdrawal and initiatives for the marine life protection; concerning CNH Industrial, the decrease of the scoring is due to the increase in total water consumption over time. The lack of information about marine life protection initiatives and use of secondary raw materials for products. Considering the Enabling index, Daimler obtained the maximum score 17/17, CNH Industrial 16/17, due to the absence of EMAS certification, and Volvo Group f 15/17, due to the absence of information about energy policy and ownership of EMAS certification. The resulting CEPE index values were the highest for Daimler (96.8), followed by CNH Industrial (93.7) and Volvo Group (77.78). Consequently, the grade assigned was A to Daimler and CNH Industrial and B to Volvo Group. The detailed calculation of the scores is in Supplementary material (sheets S11–S13).

Calibration of level 2: qualitative assessment of sustainability transition

The results of the calibration of level 2 of CIRCuS-IV on the case-study companies CNH Industrial, Daimler and Volvo Group (Supplementary materials, sheets Sheet S6, S8 and S10) were as follows. All case-study companies declared targets associated with specific SDGs (Table 4), considering at least 6–7. Specifically, the declared goals included solutions to promote the transition towards clean energy (such as reducing energy consumption and increasing the renewable resources' rate), responsible consumption and production (such as increasing the use of secondary raw materials, adopting sustainable design criteria for products), actions to achieve the carbon neutrality (such as reducing CO_2 emissions and energy consumption at production plants, increasing electric vehicles' sales, promoting alternative fuels for vehicles), actions to improve the quality of workers (such as measures for reduction of injuries frequency rate) and guaranteeing the human rights respect (such as increasing women employees). Consequently, the SDGs transition index was calculated as 7 for Daimler and 6 for CNH Industrial and Volvo Group, and grade D was assigned to all case-study companies. The detailed calculation of the SDG transition score is in Supplementary material (Sheet S11, S12 and S13).

CIRCuS-IV differs from existing frameworks and tools in several ways, offering a more comprehensive approach to evaluating circularity and sustainability in the industrial vehicles' sector. Unlike many general CE frameworks that apply across multiple industries, the key assets of CIRCuS-IV are as follows. It is designed to address the specific challenges and opportunities and proposing relevant indicators for companies manufacturing industrial vehicles; it integrates quantitative and qualitative indicators; it is a structured multi-dimensional framework built around two macro-areas (actions and strategies) divided into 11 aspects, 23 categories, and 63 sub-categories. This detailed structure ensures a comprehensive and extensive analysis, covering all relevant dimensions of circular economy implemented into the industrial vehicles industry. Additionally, CIRCuS-IV relies on publicly available data disclosed in sustainability reports, technical reports, and corporate websites, making it more accessible, practical, and transparent for companies, investors, and stakeholders. Many existing CE assessment methods require direct access to internal company data, which can be difficult to obtain. In addition, CIRCuS-IV introduces sector-specific indexes designed specifically for industrial vehicles' industry, focusing on aspects that are often neglected in general CE assessments. Overall, CIRCuS-IV is more than just an assessment tool but could be a strategic instrument that helps companies understand their position, track their progress, and identify concrete opportunities for improvement supporting their transition towards a circular and sustainable economy. While widely recognized frameworks (e.g. Science-Based Targets, ECOVADIS) focus on supporting companies in defining sustainability strategies and monitoring their performance, CIRCuS-IV complements these existing approaches by offering a specific focus on circularity, resource conservation, and product life extension, providing companies with additional insights to support their sustainability strategies. Furthermore, it has been intentionally designed to rely mainly on publicly available data, ensuring transparency, comparability, and ease of application across different organizations. This feature also allows companies to transparently share their results, for instance, on corporate websites or within sustainability reports, since the assessment is based on data that is already publicly available. According to the study performed by Sundin et al. (2015), developing sustainability indicators in collaboration with companies and their customers would enhance relevance and adoption. Future developments of CIRCuS-IV could explore synergies with established frameworks to enhance its practical applicability.

Conclusions

This study develops the CIRCuS-IV assessment tool, designed to evaluate circularity and sustainability in the industrial vehicles sector. By using semi-quantitative and qualitative indicators, it offers a comprehensive framework that covers environmental, economic, and social performance, addressing a gap in sector-specific tools. Our work also focuses on using publicly available data, such as sustainability reports and company websites, to assess sustainability performance. This approach increases transparency and accessibility, making it easier for companies to conduct evaluations without relying on proprietary data.

Therefore, although the public information availability is limited, CIRCuS-IV allows to provide an overview of the transition towards circularity and sustainability of companies manufacturing industrial vehicles and, through the application on the three case studies (CNH Industrial, Daimler, and Volvo Group), it was also possible to compare the companies' efforts towards sustainable and circular business models and performances, offering valuable benchmarks for companies to evaluate and improve their practices. The strengths of CIRCuS-IV can be highlighted as follows:

- It allows to measure circularity and sustainability for companies manufacturing industrial vehicles based exclusively on public data and information.
- It accounts for both qualitative information and quantitative data, which are inventoried and categorized.
- It allows to compare, through semi-quantitative indices, the environmental performances of companies in a consistent manner.
- It evaluates a correspondence between the actual and future actions of the companies and the circularity and sustainability principles.
- It highlights the common features and solutions adopted by different companies within the industrial vehicles' sector.
- It describes the quality of public information provided by companies.

On the other hand, CIRCuS-IV presents some limitations that need to be addressed in future research, as follows. The evaluation is not fully comprehensive, as it includes exclusively publicly available data, which are often incomplete, aggregated, or presented in a qualitative format. There is a lack of standardization in the information and data included in the sustainability reports, and this can lead to gaps or inconsistencies in the data available for assessment. As a result, CIRCuS-IV may not capture the full picture of a company's circularity and sustainability performance. Another limitation is the scoring system, which is based primarily on the presence or absence of reported data rather than on an extensive set of sector-specific quantitative indicators; consequently, the lack of specific quantitative benchmarks for the industrial vehicles sector limits the tool's ability to provide a precise measurement of sustainability and circularity progress. Additionally, CIRCuS-IV does not yet incorporate third-party verification or validation of data, which could enhance the reliability of information.

In conclusion, this study may open the perspective for further research aimed to develop a methodology that measure the circularity and sustainability transition for companies that operate in the manufacturing vehicles sector at micro-level, integrating both public and internal company data to formulate specific indices based on quantitative data. Indeed, by including punctual, company-specific information, an improved assessment tool could provide a more detailed and accurate representation of circularity and sustainability practices. In addition, although CIRCuS-IV was developed with a focus on manufacturing companies within the industrial vehicles sector, its structure, relying mainly on publicly available data, could potentially be adapted to companies of varying sizes and from different sectors. Small and medium-sized enterprises, for example, might benefit from a simplified version, while larger corporations could integrate more detailed internal data for a more robust evaluation. Future work could further investigate the necessary adjustments to make the tool fully scalable and applicable across a broader range of organizations. This framework may constitute as a reference for developing sector-specific assessment models by adapting its structure and indicators to different industries.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of 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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