Journal of Cleaner Production 420 (2023) 138439

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

An application of the UNI/TS 11820:2022 on the measurement of circularity in an electrical equipment manufacturing organization in Italy

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ARTICLE INFO

Handling Editor: Yuli Shan

Keywords:
Circular economy
Circularity indicators
Electrical equipment manufacturing
Material flow analysis
UNI/TS 11820

ABSTRACT

Data acquisition to measure circularity in processes and organizations represents a challenge, due to non-homogeneous quantification methods and different definitions related to resources consumption and waste generation. Furthermore, data interpretation has long been irreconcilable due to the absence of harmonized indicators for the measurement of circularity of processes and organizations. The UNI/TS 11820:2022 has developed (and standardized) for the first time a set of 71 indicators for the circular economy, which allows the assessment of the circularity levels in a replicable and comparable manner. The present research, after an in-depth analysis of the novel technical specification UNI/TS 11820:2022 on "Measurement of Circularity – Methods and Indicators for Measuring Circular Processes in Organizations", measures the level of circularity in an electrical equipment manufacturing organization in Southern Italy. The purpose is to test the handiness of the UNI/TS 11820:2022, improve the knowledge about the technical standard and highlight its strengths and weaknesses from the managerial, theoretical and public authorities' perspective. The UNI/TS 11820:2022 represents an essential tool to verify the effectiveness of circularity strategies at the micro (single organization) level, but it appears still complex to be applied among organizations, which do not rely on environmental and material accounting systems. Several efforts are required by academia and companies to increase the application of the standard in various NACE sectors. Moreover, although the standard aims at bridging theoretical and practical gaps towards a harmonized set of measurement tools, still some indicators seem to miss, and public authorities and universities should promote basic and advanced education in the field of circular economy measurement.

1. Introduction

Data acquisition to measure circularity in processes and organizations represents a challenge, due to non-homogeneous quantification methods and different definitions related to resources consumption and waste generation (Valls-Val et al., 2022). The transition from the linear to the circular economy requires data availability, measurement programming, comparability and replicability among different studies across industrial sectors and geographical areas (Amicarelli and Bux, 2020). However, although a plethora of studies on the global scale were addresses to explore the circularity indicators for the evaluation of sustainability strategies (Poponi et al., 2022; Ruggieri et al., 2022), the first technical standard, which provides for a transparent, replicable and unambiguous measurement of circularity, was introduced on November 30, 2022. It is based on a large circularity perspective, encompassing heterogeneous complementary approaches such as the life cycle thinking, the material flow analysis, the resource value maintenance and the value recovery, among others.

The UNI/TS 11820:2022 on the "Measurement of Circularity – Methods and Indicators for Measuring Circular Processes in Organizations" is the first standardization of a set of indicators for the circular economy measurement on the global scale. The technical specification introduces 71 indicators essential to assess, by using a 100-based rating system, the level of circularity of a single business or groups of organizations, also including public administrations, regardless of the sector or the size. The rating system allows organizations to receive a score from 0 to 100 on the level of circularity achieved at the time of measurement, with 100 expressing a maximum level of circularity. Specifically, the standard is addressed to measure circularity at the micro (e.g., single company, single local authority) and the meso (e.g., group of companies,

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https://doi.org/10.1016/j.jclepro.2023.138439
Received 29 March 2023; Received in revised form 3 July 2023; Accepted 11 August 2023
Available online 12 August 2023

regional areas, provinces) level, without considering the macro level. The UNI/TS 11820:2022 represents the synthesis of a series of standards published previously and still highly useful in calculating the environmental sustainability and circularity of industrial systems. It provides a key to reading and interpreting UNI EN ISO 14040:2021 (Environmental management - Life cycle assessment - Principles and framework) and UNI EN ISO 14067:2018 (Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification), essential for measuring the environmental impacts of the life cycle of a commodity or an organization and the carbon footprint, respectively.

The electrical and electronic equipment manufacturing sector is rather complex, and the European Commission's Joint Research Center has developed a sectoral reference document on its best environmental management practice (Antonopoulos et al., 2016). Specifically, the report adopts a process-oriented approach and develops three informative areas on the basis of the life cycle thinking approach, as follows: (i) manufacturing processes; (ii) supply chain management; and (iii) practices fostering circular economy. According to the Directive 2011/65/EU, the electrical and electronic equipment refers to the "equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1000 V for alternating current and 1500 V for direct current" (OJEU, 2011). Such manufacturing covers the production of different products and devices, such as information and communication technology equipment, household appliances, electrical tools, medical devices, etc. In Europe, the production value of electrical and electronic manufacturing [(NACE code 28 on "manufacture of machinery and equipment n.e.c." (Eurostat, 2008)] was estimated at 600 000 million euro in 2020, and Italy is the second largest producer (approx. 112 000 million euro, 18%) soon after Germany (258 000 million euro, 43%). In terms of number of enterprises, Italy represents the first European country, accounting for 18 405 companies out of 80 000 (Eurostat, 2022).

Under the environmental perspective, the adoption of circular economy strategies in the electrical and electronic manufacturing is essential, since the technological innovation and the penetration of electronics in the market has led to unprecedent volumes of electrical and electronic waste (Pan et al., 2022). The purpose of the present research is to test the handiness of the UNI/TS 11820:2022 by assessing the level of circularity in the electrical and electronic equipment manufacturing sector. It aims at improving knowledge about the technical standard and highlights its strengths and weaknesses from the managerial, theoretical and public authorities' perspective. Specifically, it calculates a set of selected circularity indicators out of the 71 proposed by the technical specification in one leading company of energy management systems for gas and steam turbines, compressors and electrical generators based in Southern Italy. The most important value for the company is the flexibility in designing and manufacturing, in accordance with customer requirements, and local and international standards. The research represents the first application of the technical standard in the scientific literature and is addressed to practitioners and academics, who are willing to apply the circularity indicators in complex organizations. Further, it adds an extra step in the testing phase of the UNI/TS 11820:2022, which requires researchers to test the technical specification in different economic activities according to the NACE.

2. Theoretical background

2.1. Definition of circular economy

Circular economy represents a sustainable business model and plays an essential role during and after crises (Wuyts et al., 2020), and the combination of different circular strategies rather than separate ones is demonstrated to have a higher impact on the resilience of organizations against future shocks (Borms et al., 2023). Such a statement is even more significant in the light of the National Recovery and Resilience Plan (NRRP) in Italy, which aims at implementing a green, ecological and inclusive transition by promoting the circular economy, the development of renewable energy sources and a more sustainable agriculture and organic waste valorization (i.e. waste-to-energy, waste-to-bioproducts) towards sustainability and resilience (Passaro et al., 2023). However, the characteristics of the circular economy business model are still blurred (Moraga et al., 2019). One of the first definitions states that the circular economy is "an approach to more appropriate waste management" (Ghisellini et al., 2016), but such a statement is limited, since the contribution of circular economy goes beyond the waste treatment and has landed to concepts of servitization (Kurpiela and Teuteberg, 2022). It should be considered that such a concept includes either the economic or the environmental perspective, as well as the social one (Geisendort and Pietrulla, 2018).

In the light of Kirchherr et al. (2017), 114 definitions of circular economy could be distinguished. On the side of core principles, the circular economy refers to the concepts of reduction, reuse, recycling and recovery, whereas on the side of aims, it relates to the sustainable development as a guarantee of environmental quality, economic prosperity and social equity. As regards the system perspective, the circular economy principles should be applied and evaluated at the micro (i.e., product, firm and/or consumer), the meso (i.e., region and/or industrial parks) and the macro (i.e., global and/or country) level. Considering the UNI/TS 11820:2022 standard, the subsequent circular economy is adopted in the current research, as follows: "Economic system which, through a systemic and holistic approach, aims to keep the flow of the circulating resources, conserving, regenerating or increasing their value, and which at the same time contributes to sustainable development". Such a definition is based on the six principles of the ISO/CD 59002 "Circular economy – Framework and principles for implementation" (International Organization for Standardization, n.d.), on the six principles of the technical standard BS 8001:2017 "Circulary economy" (Bsigroup, 2017), on the ten R (Vermeulen et al., 2019), on the three principles suggested by the Ellen MacArthur Foundation and on the seven empirical principles developed by Suarez-Eiroa et al. (2018).

2.2. Literature review on the indicators for circular economy

The procedure of measuring circularity, which adopts a system of indicators to calculate quantitative, semi-quantitative and qualitative data to define the performance of one or more organizations (Moraga et al., 2019), represents a challenge on the global scale. In recent years, several circularity indicators were developed by academics and practitioners, to better measure the effects of circular strategies on the overall circularity of products and organizations (De Pascale et al., 2021; Rossi et al., 2020).

Traditional indicators, such as those adopting the life cycle thinking approach (e.g., carbon footprint, water footprint), could not express the circular economy in its totality, since they are not designed according to all the circular principles (i.e., systems thinking, collaboration, circular value generation, circular value optimization, value preservation, innovation, awareness, inclusiveness) (Suarez-Eiroa et al., 2018). It is evident that either quantitative or qualitative indicators, as well as cross-sectional and combined multiple indicators are required to measure circularity, making its measurement complex and not homogeneous. However, suitable sets of multidimensional indicators, instead of single ones, could overcome such a limit, connecting theoretical goals and practical strategies (Suarez-Eiroa et al., 2018).

Moraga et al. (2019) have identified three measurement scopes in the light of the life cycle thinking, which is the capacity to look at products or services over the cycles of design, production, consumption, use and disposal (UNEP, 2005) and which is considered as the heart of the circular economy (European Commission, 2015). The three measurement scopes are: (i) scope 0, which measures physical properties from the technological cycles without life cycle thinking approach (Graedel et al., 2011); (ii) scope 1, which measures physical properties from the technological cycles with full or partial life cycle thinking approach (Ardente and Mathieux, 2014); and (iii) scope 2, which measures the effects from technological cycles regarding environmental, economic and/or social concerns in a cause-and-effect chain modelling (Huysman et al., 2015).

More recent studies (Poponi et al., 2022; Ruggieri et al., 2022) have developed a dashboard, whose purpose is to guide the agri-food sector toward circular economy models and sustainable development. The research conducted by Poponi et al. (2022) has identified 102 indicators classified according to the three areas of sustainability (i.e., environment, society and economy) and to different spatial dimensions (i.e., macro, meso and micro). Further, it distinguishes between air, water, soil, energy, waste, cost, value, productivity, equality, knowledge and innovation scope, highlighting the interconnection and complementarity of data required to measure circularity. Specifically, Ruggieri et al. (2022) highlight the need to collect data related to total emissions, water use, cumulative energy demand, use of primary energy (distinguishing between renewable and non-renewable energy), amount of waste sent to landfill and recycling rates. Under the qualitative perspective, the research required data related to child labor and forced or compulsory labor.

3. Materials and methods

The scope of the research is the measurement of the circularity level by using selected circularity indicators in an electronic equipment manufacturing organization. It considers as a case-study the Primiceri S.P.A., one leading company in the design and construction of electrical and electronic equipment housed in prefabricated steel for the command and control of gas turbines intended for the extraction of oil and natural gas worldwide, located in the municipality of Bari, Southern Italy. The research adopts the guidelines provided by the UNI/TS 11820:2022, as follows: (i) data acquisition; (ii) indicators of circular economy selection; (iii) results and data interpretation.

3.1. Data acquisition

The data acquisition process begins with the definition of the scope of the valuation being measured the identification of the data quality requirements (either for primary data or metadata) and the selection of the type of evaluation, which determines the selection of the set of indicators. It must be considered from the outset that the reliability of the assessment is strongly influenced by the quality, the reliability and the verifiability of the collected data. Moreover, it is important to underline that the type of data requested is determined by the type of indicators selected. Hence, the assessment of circularity from the selection of indicators to data collection is holistic, and each step is interdependent on the other. Considering that the standard recommends identifying, measuring and tracking individual input and output resource streams rather than consolidating them, the present research has acquired material flows data by adopting the mass balance approach, which is defined as a method that compares input and outputs, as well as stock levels, in space and time. If input and output data are systematically collected, such an approach can return, rather economically (in terms of time and money) a series of estimations on natural resource and raw material consumption. Specifically, the research has adopted the material flow analysis as one of the main tools based on the mass balance approach (Caldeira et al., 2019).

In the light of the UNI/TS 11820:2022 guidelines, the material flow analysis is considered as a complementary method to acquire data and is suggested among other environmental accounting tools. Such a methodological tool is defined as an existing method, approach or guideline, which adds further information and data to the circularity measurement and the evaluation model. By definition, the material flow analysis is based on the mass balance principle and represents a "systematic assessment of the state and change of materials flow and stock in space and time" (Cencic and Rechberger, 2008; Brunner and Rechberger, 2017).

The researchers have conducted systematic in-depth interviews and document collection among different key people in the organization, namely managing direction, project manager, LER production coordinator, finance manager, account manager, quality manager, procurement manager and several employees involved in the environmental, quality and financial units, as to obtain as many documents and reports as possible. Further, the authors have conducted personal observations to explore the industrial plants and communicate with employees in charge of different activities (e.g., sales, logistics, waste collection). In-depth interviews and personal communications were carried out from January 01 to March 31, which means approx. three months of systematic data collection. Among the selected documents, the authors have consulted project data, accounting and administrative documents (purchase and sale bills, balance sheets, planimetries), as well as reports, documents and datasets necessary for obtaining the ISO 14001:2015 and the ISO 9001:2015 certifications. Fig. 1 illustrates the data acquisition framework, as defined by the UNI/TS 11820:2022, with specific reference to the identification of the boundaries of the research (Section 3.1.1.), the selection of indicators to be estimated (Section 3.2.), as well as their calculation (Section 3.2.1).

Primary data refer to the year 2021 and, when required by the selected indicators, to the years 2020 (n – 1) and 2019 (n – 2). In the lack of specific primary data, not available because confidential or related to suppliers outside the system under analysis, the authors have used secondary data with reference to basic data (e.g., generic data for the sector, Italian electricity mix). Considering the nature of the organization, which undertakes orders and commissions, the authors have considered three main contracts, which represent the 100% of the entire production of the organization in 2021. Data were catalogued and analyzed in Microsoft Excel sheets.

3.1.1. *Description of the supply chain of Primiceri S.P.A*

Primiceri S.P.A (https://primiceri.it). has been operating for over 40 years in the field of planning and production of control and energy management systems for gas/steam turbines, compressors and electrical generators. Specifically, the organization is included in the represents the NACE category 271 200 related to "manufacture of electricity distribution and control equipment". On the global scale, Primiceri S.P.A is recognized as a company at the forefront in the sectors in which it operates and has acquired a large customer portfolio in Italy and abroad. Clients encompass major engineering firms, oil and gas companies, and a wide range of manufacturers, service providers and contractors. It supplies electrical equipment for turnkey systems in the context of large infrastructures (e.g., hospitals, stadiums, purifiers and all types of large and medium energy-intensive industries), and its direct and indirect export share is approx. 80% of its business volume. Primiceri S.P.A's plant is composed of 15 000 m^2 of covered area, 13 000 m^2 of external

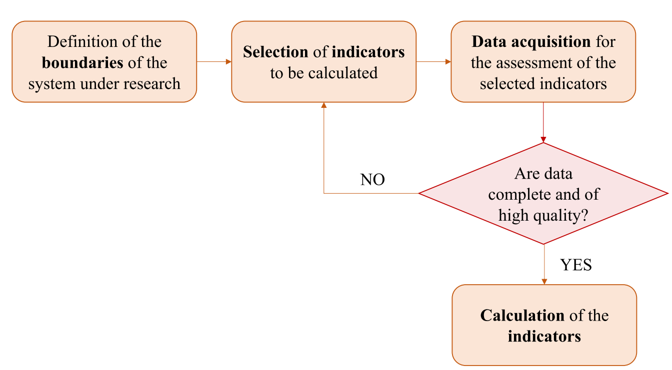

Fig. 1. Data acquisition process.
Source: Personal elaboration by the authors

area and 3000 m^2 of internal warehouse, including an air conditioned and monitored area to stock hazardous items. Its main equipment encompasses two internal cranes with a load capacity of 50 t each, four pneumatic lifters with a load capacity of 30 t each, four forklift trucks, two numerical control punch machines, one shearing machine, two bending machines and five welding machines. Among its main products, it realizes fuel gas skids, skid pumps, lube oil consoles, control panels for wind and photovoltaic plants, packaged substation and control cabins, local electrical rooms, metering and supervisory shelters, motor control centers, unit control systems, generator control protection panels, electrical panels, disconnector switch panels, power centers, automation panels and distribution panels.

Primiceri S.P.A was selected for its significant weight in its sector, and since it is committed to promote sustainable development through environmental protection, economic growth, social progress, attention to local suppliers and professional training for local employees. It is already certified according to the ISO 9001:2015 on "Quality management systems – Requirements" and to the ISO 14001:2015 on "Environmental management systems – Requirements with guidance for use", which is intended for use by an organization seeking to manage its environmental responsibilities in a systematic manner that contributes to the environmental pillar of sustainability. Since Primiceri S.P.A has a proactive attitude towards social, economic and environmental savings, the company represents one suitable test for the measurement of the circularity level by applying the UNI/TS 11820:2022.

3.2. Indicators of circular economy

The measurement system does not provide for a minimum circularity threshold value but makes it possible to evaluate the level reached by the organization, compared to the maximum level that can be reached. The UNI/TS 11820:2022 identifies 71 different indicators and distinguishes between six categories, as follows: (1) material resources and components; (2) energy and water resources; (3) waste and emissions; (4) logistics; (5) final product or service; (6) human resources, assets, policies and sustainability. Indicators are divided between core (P_c), which are mandatory, specific (P_s), of which it is mandatory to complete at least 50%, and rewarding (P_r), which are optional and whose compilation provides a higher final score, and refer to material, energy, water and economic unit of measures. The UNI/TS 11820:2022 requires filling in all the P_c indicators and at least 50% of the total P_s ones (if an odd number, round up). Further, for each of the six categories of indicators, at least 50% of each category must be completed. Last, if the minimum threshold of 50% for the selected P_s indicators is not reached, the missing P_s must be calculated (each) equal to zero. Specifically, the research has evaluated the circularity of the organization by assessing 37 out of 71 indicators (of which, 67 applicable to the organization under-research). Considering the empirical test of the technical standard, the selection of indicators was carried out based on the nature of the organization (some indicators, such as no. 18, 53, 54, 70, are not applicable to the current organization), and on the basis of available information and documents.

Table 1 illustrates the selected indicators related to the first category of material resources and components, highlighting the corresponding number (as identified by the UNI/TS 11820:2022), the typology (i.e., core, specific, rewarding, as well as quantitative, qualitative and semi-quantitative), and the formula or the description (in the case of qualitative or semi-quantitative indicators) used for their evaluation. The group of indicators related to material resources and components is composed of ten indicators, as follows: three P_c, six P_s and one P_r. Considering the opportunity offered by the UNI/TS 11820:2022 to selected at least half of the available P_s per each group of indicators, and stated that if odd round up, the authors have selected three P_s indicators out of six, whereas no P_r were included.

Table 2 illustrates the selected indicators related to energy and water resources category. Such a group of indicators is composed of five P_s, and the authors have selected three of them.

Table 3 illustrates the selected indicators related to waste and emissions category. Such a group is composed of five indicators (two P_c, two P_s and one P_r), of which the authors have selected two P_c, one P_s and zero P_r.

Table 4 identifies the selected indicators related to logistics category. Such a group is composed of six P_s indicators, out of which the authors have selected three.

Table 5 illustrates the selected indicators related to products and/or service category. Such a group is composed of 26 indicators (i.e., 24 P_s and two P_r), of which the authors have selected 12 P_s and zero P_r.

Table 6 illustrates the selected indicators related to human resources, assets, policy and sustainability category. Such a group is composed of 17 indicators (i.e., two P_c, 10 P_s and five P_r), of which the authors have selected two P_c, five P_s and one P_r.

3.2.1. Calculation of the circularity level

The level of circularity varies from 0 to 100, and the subsequent weights to the different types of indicators must be attributed: (a) 1 to P_c indicators; (b) 1 to P_s indicators; and (c) 0.5 to P_r indicators. To calculate the level of circularity, the subsequent procedure was followed: (i) sum of the values of the P_c indicators; (ii) sum of the values of the P_s

Table 2
Indicators related to the energy and water resources.

N.	Type	Measure	Formula (or description)
11	P_s	Quantitative	$\frac{\textit{Self produced electricity from ren. res. or recovery}}{\textit{Total electricity consumed}}$
13	P_s	Quantitative	$\frac{\textit{Purchased electricity from ren. res.}}{\textit{Total electricity purchased}}$
15	P_s	Quantitative	$\frac{\textit{Inbound water from reuse and recycling}}{\textit{Total water need}}$

Source: Personal elaboration by the authors on UNI (2023).

Table 1
Indicators related to the material resources and components.

N.	Type	Measure	Formula (or description)
02	P_s	Quantitative	$\frac{\textit{Inbound raw materials and secondary res. from local suppliers}}{\textit{Total inboud raw material and secondary resources}}$
03	P_s	Quantitative	$\frac{\textit{Inbound material res. equipped with tracking systems}}{\textit{Total inboud material res. equipped with tracking systems}}$
04	P_c	Quantitative	$\frac{\textit{Inbound by products and(or) secondary res.}}{\textit{Total inbound material res.}}$
07	P_c	Quantitative	$\frac{\textit{Renewable of recycled res, for packaging}}{\textit{Total packaging used}}$
09	P_s	Quantitative	$1 - \frac{\textit{Total restricted or authorised substances}}{\textit{Total inbound material res.}}$
10	P_c	Quantitative	$\frac{(\textit{Inbound resources} - \textit{Residues produced})}{\textit{Total residues produces}}$

Source: Personal elaboration by the authors on UNI (2023).

Table 3
Indicators related to waste and emissions.

N.	Type	Measure	Formula (or description)
16	P_c	Quantitative	$1 - \frac{Urban\ and(or)special\ waste\ sent\ to\ landfills}{Total\ urban\ and(or)special\ waste\ generated}$
17	P_c	Quantitative	$\frac{Municipal\ and(or)special\ waste\ collected\ separately}{Total\ urban\ and(or)special\ waste\ generated}$
19	P_s	Qualitative	Has the organization carried out the assessment of its carbon footprint according to UNI EN ISO 14064 in year n and/or n-1 and/or n-2?

Source: Personal elaboration by the authors on UNI (2023).

Table 4
Indicators related to logistics.

N.	Type	Measure	Formula (or description)
22	P_s	Quantitative	$\frac{Waste\ treated\ at\ local\ valorisation\ plants}{Total\ waste\ treated\ at\ valorisation\ plants\ (local\ or\ not)}$
25	P_s	Quantitative	$\frac{Actual\ load\ capacity\ used\ by\ vehicles\ (round\ trip)}{Total\ capacity\ of\ the\ vehicles}$
26	P_s	Quantitative	$\frac{Number\ of\ employees\ adhering\ to\ sustainable\ mobility}{Total\ employees}$

Source: Personal elaboration by the authors on UNI (2023).

indicators; (iii) sum of the values of the P_r indicators, which was multiplied by 0.5; (iv) addition of the sums of P_c, P_s and P_r; and (v) calculation of the level of circularity by dividing the sum of P_c, P_s and P_r by the total number of P_c and P_s indicators. Equation (1) formalizes the mathematical model for calculating the level of circularity:

$$LC = \frac{\sum P_c + \sum P_s + 0.5 \sum P_r}{n\ P_c + nP_s} \tag{1}$$

Specifically, the denominator consists of the entire number of P_c and P_s applicable to the organization under study. Therefore, although the technical standard refers to a minimum number of indicators that must necessarily be calculated, it always relates the numerator (i.e., the sum of the circularity values achieved in the light of the calculated indicators) to the entire number of calculable P_c and P_s indicators.

As suggested by the UNI/TS 11820:2022, the level of circularity was calculated with reference to each category of indicators (i.e., indicators of material resources and components, indicators of energy and water resources, indicators or waste and emissions, indicators of logistics, indicators of final product or service, indicators or human resources, assets, policies and sustainability), as to more precisely evaluate the areas of intervention. Last, data were rounded to the second decimal and the levels of circularity were graphically represented, according to the radar representation of the indicators' values.

4. Results and discussion

4.1. Circularity assessment in the organization

The level of circularity reached by the organization under-research was estimated on the basis of the assessment of the selected indicators (Section 3.2.) and applying the equation (1). Table 7 illustrates the single value recorded per each selected indicator.

In 2021, by considering the entire set of indicators as outlined by the UNI/TS 11820:2022, the organization's circularity level was equal to 36.70%. Remembering that the UNI 11820:2022 states that "the measurement system does not provide for a minimum circularity threshold value but makes it possible to evaluate the level reached by the organization, compared to the maximum level that can be reached", the global level recorded confirms the proactive environmental protection approach of the observed organization, as well as a good starting point towards circular and sustainable performances in the future. Moreover, boosting the usefulness of the tool applied, it is possible to evaluate several rooms for improvement. Specifically, it results that the level of circularity, per each group of indicators, is: (a) 47.33% for natural resources and components; (b) 15.98% for energy and water resources; (c) 47.50% for waste and emissions; (d) 19.39% for logistics; (e) 22.54% for products and/or services; and (f) 67.50% for human resources, assets, policy and sustainability. Fig. 2 graphically represents the circularity level of the organization according to the "strongly recommended" radar chart, distinguishing per each indicator category (UNI, 2023).

4.2. Managerial and theoretical implications

Soon after the document collection and the in-depth evaluation of the circularity indicators, the active role of the managing director and the project managers of the organization was crucial in interpreting

Table 5
Indicators related to products and/or services.

N.	Type	Measure	Formula (or description)
29	P_r	Quantitative	$\frac{Outbound\ resources\ with\ a\ tracking\ system}{Total\ outbound\ resources}$
36	P_r	Quantitative	$\frac{Products\ and\ services\ sold\ with\ supporting\ information\ for\ repair}{Total\ sold\ products}$
40	P_s	Quantitative	$\frac{Quantity\ of\ products\ generated}{Quantity\ of\ resources\ employed}$
41	P_s	Quantitative	$\frac{Value\ of\ products\ and\ services\ from\ local\ suppliers}{Total\ value\ of\ products\ and\ services}$
43	P_s	Qualitative	Has the organization made investments in the circular design of its products and/or services in years n and/or n-1 and/or n-2?
44	P_s	Qualitative	Has the organization made investments in circular design of its processes in years n and/or n-1 and/or n-2?
45	P_s	Qualitative	Has the organization made investments in circular design of its assets in years n and/or n-1 and/or n-2?
46	P_s	Quantitative	$\frac{Investment\ in\ R\&D\ linkes\ to\ the\ circular\ economy}{Total\ investment\ in\ R\&D}$
47	P_s	Quantitative	$\frac{Inbound\ resources\ coming\ from\ industrial\ symbiosis}{Total\ of\ inbound\ resources}$
48	P_s	Quantitative	$\frac{Outbound\ resources\ valorized\ with\ industrial\ symbiosis}{Total\ outbound\ resources}$
49	P_s	Quantitative	$\frac{Inboud\ water\ resources\ from\ industrial\ symbiosis}{Total\ inbound\ water\ resources}$
50	P_s	Quantitative	$\frac{Outbound\ water\ res.\ valorized\ with\ industrial\ symbiosis}{Total\ outbound\ water\ resources}$
51	P_s	Quantitative	$\frac{Inboud\ energy\ resources\ from\ industrial\ symbiosis}{Total\ energy\ water\ resources}$
52	P_s	Quantitative	$\frac{Outbound\ energy\ res.\ valorized\ with\ industrial\ symbiosis}{Total\ outbound\ energy\ resources}$

Source: Personal elaboration by the authors on UNI (2023).

Table 6
Indicators related to human resources, assets, policy and sustainability.

N.	Type	Measure	Formula (or description)
56	P_s	Qualitative	Has the organization already carried out staff training on the circular economy in the current year and in the two years before?
57	P_c	Semiquantitative	Which is the average energy performance index of buildings for civil use of the organization? Class A = 100%; Class B-C = 50%; Class D-F = 25%; Class G = 0%.
59	P_c	Semiquantitative	Has the organization developed and implemented a circular economy strategy?
60	P_s	Qualitative	Does the organization carry out external communication of its sustainability and circularity performance (through sustainability reports, non-financial statements, etc.)?
67	P_s	Qualitative	Has the organization planned to carry out internal staff information and training activities on the circular economy?
68	P_s	Qualitative	Has the organization carried out external training and information plans on the circular economy aimed at stakeholders?
69	P_r	Qualitative	Does the organization have an energy efficiency plan?
71	P_s	Qualitative	Does the organization adopt an Environmental Management system?

Source: Personal elaboration by the authors on UNI (2023).

results. It should be highlighted their essential knowledge of the organization processes in identifying the main criticalities, as well as in brainstorming possible solutions and paths for interventions towards sustainability. The application of the theoretical concepts, which are proposed by the researchers, to the practical reality, which is in the hands of the management, is the necessary blend to make full use of the utility of the UNI/TS 11820:2022.

In the natural resources and components category, the indicators no. 2 on raw materials and secondary material resources purchased from local suppliers and the indicator no. 4 on inbound by-products and secondary material resources compared to the total material resources have recorded values lower than 10%. Such a critical parameter highlights the need to boost contracts with local suppliers, as well as the need to rely on secondary raw materials instead of virgin ones.

Further, it results that the organization should enhance the circularity in the field of energy consumption, with specific reference to the increase in the electricity generated by renewable resources. According to the indicator no. 11, the organization could improve its circularity by increasing the amount of electricity autogenerated from renewable resources. At current, the organization has installed a photovoltaic rooftop for a capacity of 108 kW, and the value of the indicator no. 11 was estimated at 26%. However, such an amount is expected to grow, since the organization has planned to expand the photovoltaic system up to 300 kW, which can actually boost the circularity level of the selected indicator to about 98%. The expected increase in the renewable energy production could allow the organization to cover its entire electricity needs and avoid any outsourcing of energy. As regards the purchase of

Table 7
Circularity assessment per indicator.

Indicator group	No.	Numerator	Unit	Denominator	Unit	Value
Natural res. and components	02	432 026	kg	1 249 934	kg	0.34
	03	1 187 437	kg	1 249 934	kg	0.95
	04	80 361	kg	1 249 934	kg	0.07
	07	80 361	kg	81 968	kg	0.98
	09	12 499	kg	1 249 934	kg	1 – (0.01) = 0.99
	10	(1 249 934–87 600)	kg	1 249 934	kg	0.93
Energy and water resources	11	117 647	kWh	445 972	kWh	0.26
	13	Estimated from the Italian energetic mix				0.38
	15	255	m^3	1600	m^3	0.16
Waste and emissions	16	4600	kg	87 600	kg	1 – (0.05) = 0.95
	17	81 600	kg	87 600	kg	0.95
	19	Qualitative = NO				0
Logistics	22	Semiquantitative = NO				0.98
	25	N/A				0
	26	9	n	49	n	0.18
Products and/or services	29	1 162 334	kg	1 1623 34	kg	1
	36	581 167	kg	1 162 334	kg	0.50
	40	1 162 334	kg	1 249 934	kg	0.93
	41	2 375 440	euro	8 520 000	euro	0.28
	43	Qualitative = YES				1
	44	Qualitative = YES				1
	45	Qualitative = YES				1
	46	N/A				0
	47	N/A				0
	48	N/A				0
	49	N/A				0
	50	N/A				0
	51	N/A				0
	52	N/A				0
HR, assets, policy and sust.	56	Qualitative = YES				1
	57	Semiquantitative = Class C = 50%				0.50
	59	Semiquantitative = CE strategies, targets, and objectives				0.75
	60	Qualitative = YES				1
	67	Qualitative = YES				1
	68	Qualitative = YES				1
	69	Qualitative = YES				1
	71	Qualitative = YES				1

Note: N/A means that indicators have been considered to reach at least 50% of the P_s per each indicators' category, as outlined by the UNI/TS 11820:2022 [i.e., "For each of the six categories of indicators, at least 50% of the indicators contained therein must be completed (in the event of an odd number, round up). If the minimum threshold of 50% for the specific indicators calculated is not reached, the missing specific indicators must be calculated (each) equal to zero"].

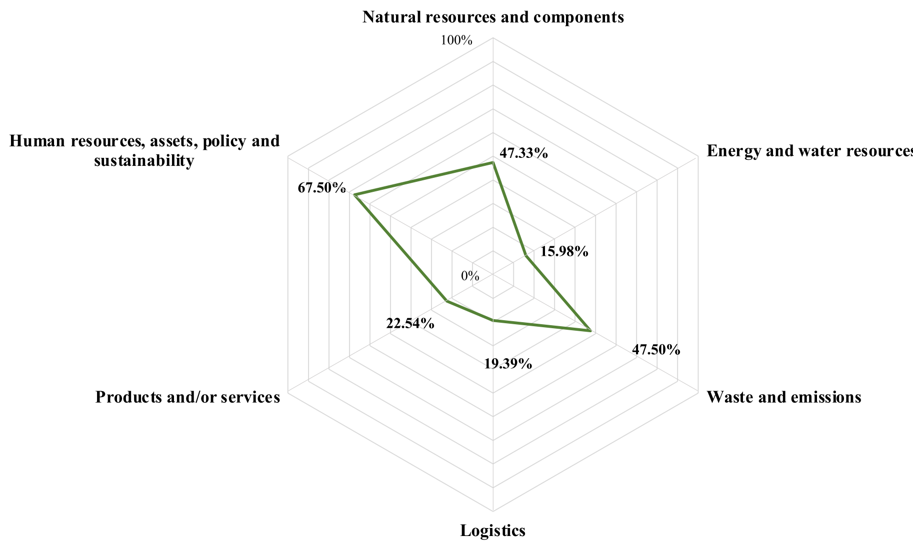

Fig. 2. Radar representation of the level of circularity per indicator.
Source: Personal elaboration by the authors.

electricity from the national system, it results that the indicator no. 13 is equal to the percentage of renewable energy included in the national electricity mix. Further, considering the indicator no. 13, although the organization owns a rainwater filtering tank, which returns purified water to the consortium network for an amount of approx. 315 mc, solely the amount of water collected for the fire tank was considered for the assessment of the indicator.

In the light of the indicator no. 25, it was quite complex estimating the actual load capacity used by vehicles in terms of round trips, considering that the organization outsources logistics and does not own its fleet of vehicles for inbound and outbound transportation. Although outsourced vehicles optimize their cargo by traveling through multiple companies, such an indicator highlights the need for organization to invest on sustainable mobility (Alp et al., 2022; Varese et al., 2022). Additional considerations could be done with reference to the indicator no. 26, which evaluates the number of employees adopting sustainable mobility initiatives. On the one side, it results that no municipal, provincial or regional initiatives were adopted in the area where the organization is located, nor initiatives were promoted by local workers' associations. However, in the absence of external initiatives, the problem could be overcome by promoting initiatives within the organization, according to a bottom-up approach. At current, an interesting number of employees have autonomously organized themselves for car-sharing, for instance those living in the same town and coming from the same city. However, it is difficult to reach the highest level in such an indicator, since, on the one hand, there is the limit of the location of the organization (i.e., industrial area, difficult to be reached with sustainable means of transport such as, for example, bicycles or electric scooters). On the other hand, the achievement of high levels of circularity in relation to this indicator would require that all (or many) workers live in close proximity to each other and are able to carry out, for instance, car-sharing. One opportunity to boost bottom-up initiatives of car-sharing among employees it to let them understand the rebound effects of re-spending the saved money from fuel consumption, which can be from 70 to 80%, for the purchase of other goods and services (Arbeláez Vélez, 2023).

Under the theoretical perspective, the application of the UNI/TS 11820:2022, in the absence of suitable systems of measurement of resources (indicator no. 33) within the organization, represents the starting point for implementing circular economy strategies. Qualitative indicators allow organization to increase their circularity level by collecting easier information compared to quantitative indicators. Qualitative indicators are simpler to be evaluated, since they require a binary answer (yes or no) and companies are aware of the items, which should be calculated. For instance, the indicators no. 42, 43 and 44 allow the achievement of 100% of circularity by declaring that an organization has developed circular economy strategies, has enacted investments in circular economy (e.g., increase in the number of photovoltaic panels or hiring of workers dedicated to separate waste collection). Moreover, it appears rather simple to evaluate items, which are susceptible to an unequivocal economic evaluation, such as the electricity consumption (indicator no. 11, 13). It demonstrates that some variable should be interpreted according to their (potentially) obtainable economic value.

On the other side, from the proposed assessment of the circularity level, it was highlighted the current complexity of measuring some indicators, especially in the light of the absence of an internal structured material accounting system. Considering their slight diffusion among small and medium companies, several items were identified as difficult to be measured, such as "self-produced secondary material resource" or "upcycling" or "reverse logistics", which still appear innovative concepts among employees (Amicarelli and Bux, 2023). Although the level of awareness and perception of the measurability of the circular economy increases as the level of education increases or as the age of the users decreases, training and education among managers and workers is required (Stucki et al., 2023). Hence, in the light of the indicator no. 67 and 68, which suggest staff training on the circular economy, possible opportunities could consider teaching programs based on the concepts of environmental accounting, material flow analysis and life cycle thinking. Further, the lack of the assessment of the carbon footprint, as well as the absence in the adoption of industrial symbiosis practices, appear to be a penalty for the organizations under investigation. Such a perception is corroborated by the presence of three indicators related to the carbon footprint (indicator no. 19, 20, 21) and nine indicators related to the industrial symbiosis (indicators no. 47, 48, 49, 50, 51, 52, 53, 54, 55), which together represent the 17% of the total indicators proposed by the UNI/TS 11820:2022. Although such indicators are P_s and P_r, which make them voluntary compared to the P_c, it appears rather an address of commitment for the achievement of high rates of circularity among companies.

4.3. Policy implications

The UNI/TS 11820:2022, which represents one of the first outputs of the UNI1608856 project, is in its testing phase in different economic activities according to the NACE, and some considerations for interventions by public authorities could be proposed in the light of the current research, as well as according to rare studies on the topic (Amicarelli and Bux, 2023; Vola et al., 2023).

First, it should be underlined that the technical standard aims at bridging several circularity measurement gaps already identified in literature (Ruggieri et al., 2022), such as the lack of a harmonized system of indicators (Poponi et al., 2022, 2023) and the fragmentation in circular economy definitions (Kirchherr et al., 2017). Hence, the technical standard must be interpreted as a framework that encompasses different economic, environmental and social interests and must, at the same time, maintain a certain simplicity of calculation and interpretation. During its historical evolution, the UNI/TS 11820 should have included a higher number of indicators, representing a complication in data collection and calculation process by organizations. The selected number of indicators (n = 71) tries to respond on the one hand to the needs of completeness, and on the other hand to those of simplification. This, of course, to the detriment of some indicators that were eliminated and whose lack can represent a measurement limit. For instance, in the current version of the technical standard, no indicator, neither quantitative nor qualitative, refers to the use of the water footprint or to the evaluation through the life cycle assessment, which could be penalizing for organizations that, in recent years, have worked in order to obtain these internationally recognized certifications (and rewarding in calls for access to public funding). If the carbon footprint indicator is explicitly mentioned, an open point concerns the possible insertion, at least, of explicit reference to the water footprint assessment.

Secondly, the application of the technical specification suffers from the still low awareness of circularity concepts among both managers and employees (Vola et al., 2023). Amicarelli and Bux (2023) have revealed a general negative perception on the ease of measuring circularity according to the UNI/TS 11820:2022, with regards to some variables such as "self-produced secondary material resources" or "upcycling" or "reverse logistics", which still appear as concepts with blurred boundaries among human resources. However, it was pointed out that the level of awareness on the technical specification increases as the level of education increases, or as the age of the users decreases, and for this reason public authorities should implement education plans within and without the boundaries of the organization. One possible opportunity could be the involvement of either university students, which are "healthy carriers" of inspiration, hope and culture toward sustainable development, or managers and stakeholders in specific tasks related to the evaluation of the circular economy in organizations. For instance, through internship programs, collaborations and partnerships between universities and private companies or between small entrepreneurial companies and large corporations (Veleva and Bodkin, 2018).

Also, public authorities should promote education in the field of international certification schemes for energy and environmental management (such as the ISO 50001), as well as for the sustainability reports and the non-financial statements, since their knowledge is required to apply and interpret the UNI/TS 11820:2022 (Vola et al., 2023).

As regards the strengths of the technical specification, it should be noted that it allows the identification of benchmarking between organizations (i.e., comparability), as well as the great replicability of the methodologies used for data collection and for the evaluation of the indicators. Furthermore, the UNI/TS 11820:2022 embraces the most recent circular economy business addresses, such as those related to servitization (Kurpiela and Teuteberg, 2022), since it refers to either manufacturing companies, service organization and manufacturing-service organizations (Vola et al., 2023). One additional point, which could increase its utility in terms of interpretation and benchmarking, could be its application in conjunction with reading the most recent technical report UNI/TR 11821:2023 on "Collection and analysis of good circular economy practices".

5. Conclusions

The research, after an in-depth analysis of the circular economy concept and the main circular indicators adopted in literature, applies the novel technical specification UNI/TS 11820:2022 on "Measurement of Circularity – Methods and Indicators for Measuring Circular Processes in Organizations". It was applied to measure the level of circularity in the electrical and electronic equipment manufacturing sector by calculating for the first time the circularity indicators in a leading company of design and construction of electrical and electronic equipment in Southern Italy. The current application of the UNI/TS 11820:2022 provides an original application of the experimental technical specification used as a monitoring framework. Before converting the document into an international standard (ISO), it is necessary to conduct suitable tests in different typologies of organizations and sectors, as to verify strengths and weaknesses of the current version. The monitoring activities of UNI/TS 11820:2022 within the under-development ISO 59000 is very important to finally offer standardized guidance for organizations, regardless of their size, sector or region, to switch from linear to circular business models and create value networks.

To develop the UNI/TS 11820:2022 further, a joint effort by academia and companies is needed, as to test the effectiveness (and the handiness) of its application in various NACE sectors. Although the standard aims at bridging theoretical and practical gaps towards a harmonized set of measurement tools, still some indicators seem to miss, such as those reported in the life cycle assessment (ISO 14040:2006) and the water footprint (ISO 14046:2014). Further, public authorities and universities should promote basic and advanced education in the field of circular economy (and its measurement), since there is still low awareness of circularity concepts among both managers and employees at all levels, from small to medium and large enterprises. Also, companies should develop internal material accounting systems, which would represent the basis to calculate the UNI/TS 11820:2022 indicators.

Although the current research represents a single case study and suffers from lack of representativeness for the entire electrical equipment manufacturing sector, it is the first application in the scientific literature, and can therefore lay the foundations for the researchers, whose aim is to identify a harmonized system of indicators towards circularity and sustainability.

CRediT authorship contribution statement

Vera Amicarelli: Conceptualization, Methodology, Data curation, Resources, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Maurizio Primiceri:** Supervision. **Enrico Misino:** Data curation, Validation, Investigation, Resources, Supervision. **Christian Bux:** Conceptualization, Methodology, Data curation, Resources, Investigation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

Acknowledgements

The authors thank the employees involved in the environmental, quality and financial units for their assistance in data acquisition and would like to express sincere gratitude to the editor and the anonymous referees for their insightful, precious and constructive comments.

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