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The challenge of measuring innovation types: A systematic literature review

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A B S T R A C T

Measuring innovation has long posed a significant challenge and has been the subject of extensive scientific research. Various definitions and measures of innovation exist, and each measurement approach faces limitations. This research aims to conduct a systematic literature review to expose the tendencies in measuring various types of innovation, thereby revealing different approaches, challenges, and limitations. This paper systemises and groups indicators, highlighting similarities and differences in measuring various innovation types. The systematic literature review includes 172 papers from the WoS Core Collection and Scopus databases, presenting innovation indicators across nine types of innovation: product, process, service, technological, management (or organizational, administrative), business model, supply chain, green (or environmental, eco), and open innovation. The analysis reveals that researchers often employ a broad range of indicators, many of which are not even closely aligned with specific innovation types. Accordingly, this paper offers recommendations for selecting indicators tailored to innovation type.

Introduction

There is broad consensus that innovation contributes to economic and productivity growth in countries. It is also a crucial factor enabling companies to remain competitive and achieve sustainable competitive advantages. However, measuring innovation has long posed a significant challenge and has been the focus of extensive scientific research (Hong et al., 2012; Rammer & Es-Sadki, 2022; Salazar & Holbrook, 2004).

Innovation refers to 'the introduction of a new product, service, or process to the external market or the introduction of a new device, system, program, or practice in one or more internal units' (Walker et al., 2015). Newness or novelty is a core feature of innovations. Schumpeter identified types of innovation by proposing that innovations involve the introduction of new products, new methods of production, new markets, new sources of supply, and new market structures or organisational forms. Consequently, the literature includes numerous evaluations of product innovation (Galindo & Méndez, 2014; Markovic & Bagherzadeh, 2018; Yildiz et al., 2024), process innovation (Antonioli et al., 2021; Hussen & Çokgezen, 2020; Pålsson & Hellström, 2023), marketing innovation (Abu Rumman et al., 2019; Aiello, 2013), and organisational innovation (J. Cheng et al., 2024; Walker et al., 2015). Some of these types of innovation are combined and researched under the umbrella of technological innovation assessment (Yi et al., 2021; Zhang, 2022). The scientific literature further explores innovation evaluations related to other types of innovation, such as service innovation (Aas & Pedersen, 2011; Kitsios & Grigoroudis, 2020; Yang et al., 2018), green or eco-innovation (García-Granero et al., 2018; Ghisetti & Pontoni, 2015; Kiefer et al., 2017), open innovation (Al-Belushi et al., 2018), supply chain innovation (Abdallah et al., 2021; Ojha et al., 2016).

Measuring different types of innovation is challenging due to varied theoretical frameworks, measures, and sources of information on innovation guiding measurement. The input–process–output–outcome (IPOO) model is the dominant framework used in innovation measurement (OECD, 2018), facilitating innovation measurement through the stages of the innovation process (Goffin & Mitchell, 2010). Input-oriented metrics assess the resources dedicated to innovation. These metrics include R&D spending, the number of personnel engaged in innovation-related activities, and technological investments.

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Output-oriented metrics evaluate the results and provide tangible evidence of innovation efforts. These metrics include patent filings, new products and services, and innovation efficiency. Activity-related metrics measure the range and depth of activities specifically aimed at initiating and achieving innovation. Outcome or impact measures capture the broader effects of innovation on firm performance, such as changes in productivity, competitiveness, and market position.

While this framework is useful and guides innovation measurement, it suffers from oversimplification of innovation processes, a focus on tangible metrics, a limited perspective on outputs, and neglect of external collaboration. First, the IPOO model represents innovation as a linear sequence—input, process, and output—whereas innovation is often non-linear, iterative, and involves feedback loops. Furthermore, it tends to overlook broader environmental, organisational, and cultural factors influencing innovation, such as market dynamics, competition, and regulatory changes, contributing to oversimplification of innovation processes. Second, while the model focuses on quantifiable metrics such as R&D expenditure and the number of patents or products launched, it neglects intangible aspects such as creativity, organisational culture, and knowledge creation, failing to capture learning, experimentation, and adaptation processes crucial in innovation. Third, the IPOO model emphasises immediate outputs, such as new products or patents, while ignoring long-term impacts such as sustained competitive advantage, market disruption, or ecosystem development. This approach may focus on prioritising easily measurable outcomes, such as patent numbers, over more meaningful innovations that are harder to quantify, such as business model innovations or customer experience improvements. Finally, as companies increasingly adopt open innovation paradigms, the IPOO model's assumption that innovation processes occur primarily within organisational boundaries does not account for the role of external collaborations, partnerships, or networks (e.g., open innovation, co-creation with customers) (Chesbrough & Bogers, 2014). This theoretical framework thus guides the selection of measures, but the nature of the measures can also influence the result.

Armbruster et al. (2008) noted that different types of innovation measures yield different results. They proposed that innovation can be measured by aggregate measures, use- or change-type measures, extent-of-use-type measures, and measures related to innovation features. For example, to measure organisational (i.e., administrative) innovation, such as a hybrid work model with both on-site and remote work modes, an aggregate measure would question whether a firm's new or improved organisational structures, policies, or procedures significantly differ from previous organisational structures and have been introduced during the last year. Although the hybrid work model is not directly measured, it falls under the category of new or improved organisational structures, policies, or procedures, allowing such questions to capture the introduction of hybrid work and other organisational innovations. A use- or change-type measure would ask whether the organisation introduced a hybrid work model, producing a dichotomous measure. Further, the extent of use of the hybrid work model within the organisation can be examined through a Likert-type ordinal measure, indicating the extent of used potential of organisational innovation. Finally, one may operationalise hybrid work into constitutive dimensions and probe for each dimension or multiple manifest items constituting each dimension. All of these approaches yield different results (Armbruster et al., 2008). Such examples reveal that innovation measurement can be conducted at varying levels of granularity. The multiple manifest indicators-based approach provides the most detailed insight and presupposes surveys as data sources. However, surveys are only one of several sources of innovation measurement data.

Innovations are measured using surveys, statistical data, patent data, and data collected using online algorithms, with each source influencing results through unique strengths and weaknesses. Surveys are valuable for collecting both qualitative and quantitative information directly from stakeholders such as companies, employees, customers, or industry experts. Statistical data encompasses a broad range of quantitative information that can be analysed to derive insights into a company's innovations; common sources include financial reports, R&D spending details, revenue from new products, and other innovation-related financial metrics. Patent databases serve as a rich source of information on a company's technological innovation, allowing various innovation aspects to be analysed based on the number of patents filed and granted as well as their impact through citations. Patents reflect the diversity of technological areas covered, indicating innovation breadth, while patent analysis reveals patent activity across different countries, suggesting the scale and global reach of innovation efforts. Finally, web mining involves extracting and analysing large datasets from websites, social media platforms, and other online sources. The same type of innovation can be measured using multiple data sources. For example, product innovations can be measured using survey data (Evangelista et al., 2001; Rouvinen, 2002), company reports, patent information, and web scraping and processing of company website data (Kinne & Lenz, 2021). Each approach has unique strengths and weaknesses (Rammer & Es-Sadki, 2022). However, the outcome of measurement partly depends on the data used (Héroux-Vaillancourt et al., 2020).

In summary, measuring innovation is challenging due to the theoretical frameworks that guide measurement, the various types of measures, and the sources of information on innovation. The diversity of options introduces high complexity to innovation measurement efforts. Consequently, the results of research that adopt idiosyncratic approaches to innovation measurement, grounded in a specific set of measures, information sources, and theoretical frameworks, are often difficult to compare. This research aims to conduct a systematic literature review to reveal trends in the measurement of various types of innovation, as well as to uncover different approaches, challenges, and limitations. This paper seeks to systemise and group indicators to highlight similarities and differences in measuring different types of innovation, contributing to existing theory and practice in several ways.

First, innovation is commonly divided into types such as product, process, technological, and organisational innovation. Existing classifications vary among researchers and fields, creating a fragmented understanding. By examining these classifications and identifying links between them, as suggested by Ko and Lu (2010), this research provides a systematic analysis of the similarities and differences in measuring these dimensions. Through the synthesis and categorisation of innovation indicators, this study adds depth to the academic discourse on innovation metrics.

Second, despite the shortcomings noted above, the majority of firm-level innovation research relies on the input–process–output–outcome model. Due to the model's comprehensiveness, scholars tend to use single-type measures related to input, output, activities, or outcomes to capture the extent of a particular type of innovation within a company. This study contributes to the ongoing discourse by demonstrating that, as research evolves, innovation measures become increasingly difficult to classify strictly into input or output categories. The research presents a unique classification of innovation indicators, offering a three-level aggregation system (major, moderate, minor) that enhances the clarity and applicability of innovation measures across various types of innovation.

Third, the study summarises disparate approaches to measuring innovation by developing a classification system that applies to nine types of innovation (product, process, service, etc.). It also highlights the need for a standardised and validated system for innovation indicators, addressing a gap in the academic literature where previous measures were often fragmented and lacked sufficient validation. This work can thus serve as a foundation for further theoretical development and empirical validation.

Fourth, this research provides a framework for practitioners to assess innovation more accurately by identifying specific indicators for each type of innovation. It aids companies in aligning innovation efforts with strategic goals and enhancing decision-making. By systemising and classifying indicators, this research provides organisations with practical guidelines for applying relevant metrics to evaluate innovation across different areas.

The paper is structured as follows. Section 2 describes the methodology employed for the analysis of papers. Section 3 presents an overview and comparison of indicators used to measure nine types of innovation (i.e., product, process, service, technological, management, business model, supply chain, green, and open). Section 4 describes the data sources researchers use to get information about company innovation. Section 5 discusses limitations in current innovation measurement practices and suggests directions for future research. Section 6 provides a discussion of issues related to innovation measurement and presents recommendations on selecting innovation indicators. The paper ends with the main conclusions derived from this research.

Methodology

The papers for the systematic literature analysis were selected from the WoS Core Collection and Scopus databases, the leading and most reputable global citation databases. These databases contain high-quality journals, ensuring the reliability of the results presented in the papers. Since the objective of this research is the measurement of a company's innovation, papers from these databases are selected based on the following criteria:

- Keywords in the papers' titles, keywords, and abstracts: (innovation or innovative or innovativeness) and (estimation or evaluation or measurement) and (indicator or measure or variable) and (company or firm or enterprise or corporate);
- Document type: limited to Articles or Review Articles;
- Category: limited to Management, Business, Economics, Social Sciences, or Multidisciplinary Sciences;
- Publication date: since 2010;
- Language: English.

The list of the articles used in this study was created on March 21, 2024. The paper selection process is presented in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram (Page et al., 2021) in Fig. 1.

1557 articles are identified in the WoS Core Collection and 1815 articles in the Scopus database. After aggregating these lists of papers and eliminating duplicates, a total of 2619 papers were obtained. Further analysis is based on examining the abstracts and keywords of these papers, according to the following eligibility criteria to identify core papers for comprehensive analysis:

- Although the primary list of papers formed includes the keywords filtering the papers focused on companies' innovation measurement, a significant number of papers still measure innovation at the regional, country, or city level. Since the indicators for innovation measurement at the mezzo or macro levels differ, only papers focused on innovation at the company level are deemed eligible.
- Numerous papers mention 'innovation' in their abstract in various contexts (e.g., innovative method) or use the term in fragmented ways without aiming to measure it. Moreover, 'innovation' is not included among the keywords of the paper. These papers are also excluded from further analysis.
- Many papers analyse company innovation in general (there is no indication of a specific type of innovation). Such papers are outside the scope of this research and are also excluded from further analysis. The analysis of such papers will be the objective of our future research. This research is limited to the analysis of papers that indicate the type of innovation, such as product innovation, process innovation, or green innovation.

After screening papers based on these criteria, the following innovation types are identified: technological, product, service, organisational, management, administrative, process, marketing, packaging, employee, work behaviour, green, environmental, eco-innovation, open, supply chain, consumer, capital, digital, financial, sustainable, business model, social, user, and knowledge. However, several innovation types are investigated in a few papers, necessitating revision to the analysis of their measurement and explaining why such types of

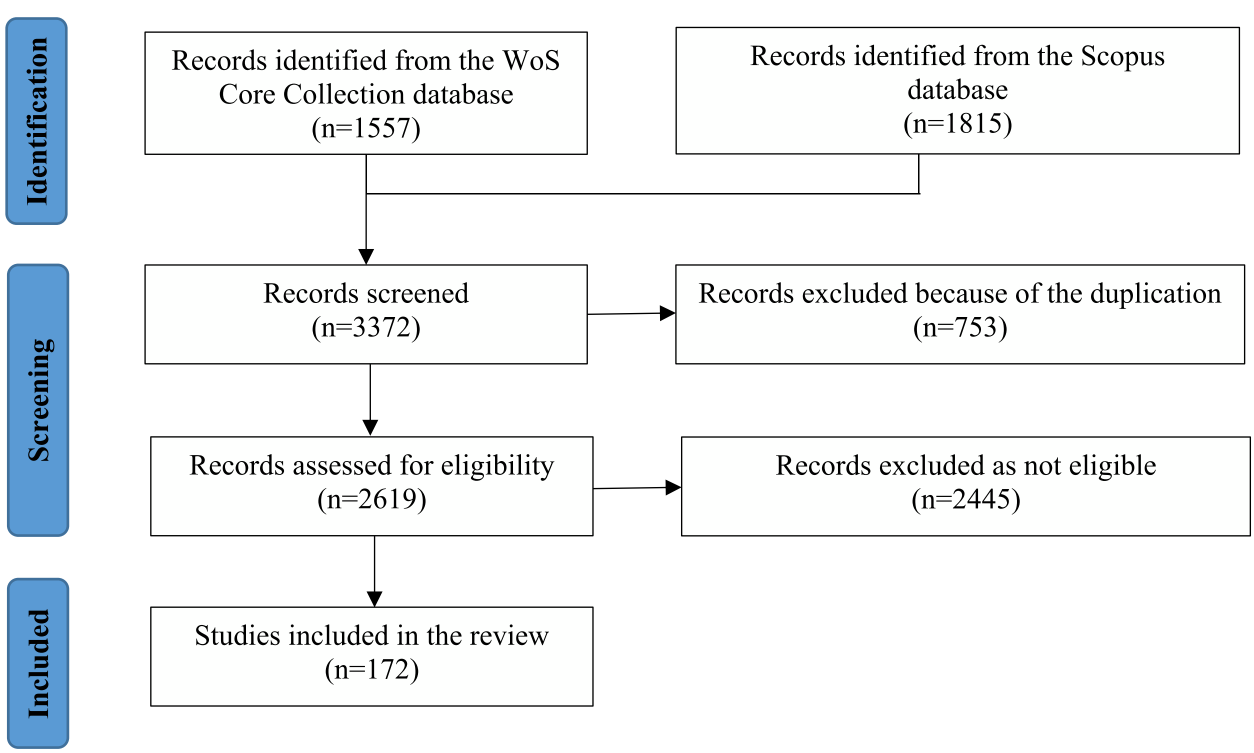

Fig. 1. Flow diagram of the paper selection process for the systematic review.

innovation are excluded from further analysis. Thus, the further research is limited to the analysis of nine types of innovation:

- Product innovation (22 papers);
- Process innovation (18 papers);
- Service innovation (14 papers);
- Technological innovation (29 papers);
- Management, organisational, or administrative innovation (13 papers);
- Business model innovation (seven papers);
- Supply chain innovation (five papers);
- Green, environmental, or eco-innovation (51 papers);
- Open innovation (13 papers).

In total, 172 articles were determined relevant for the comprehensive review. The analysis seeks to identify indicators used to measure specific innovation types and the data sources most commonly used in research.

Given the diversity of indicators used in various research, it is necessary to adopt a certain system for them. Accordingly, this research classifies indicators at three levels of aggregation:

- *Minor*: indicators are presented using main keywords from survey questions or secondary data sources. The list of these indicators, along with references, is presented in Appendix A.
- *Moderate*: indicators (their keywords) are classified into 16 categories based on the aspects they reveal, presented in Section 3 and Appendix A.
- *Major*: 16 categories are grouped into four clusters, as described below.

Considering the variety of indicators used to measure innovation, the following 16 categories of indicators are used in the analysis for moderate-level aggregation:

- *Materials*: indicators that consider various aspects of materials used to make products, such as recyclable, reusable, non-polluting/toxic, or remanufactured materials, innovative components, parts, products, or less material.
- *Natural resources*: indicators that observe the resources required to make a product or provide a service, such as the consumption of water, electricity, coal, oil, and renewable energy.
- *Technology*: indicators related to the company's technology, such as green, cleaner technology.
- *Finance*: grouping various company financial indicators, such as investment, revenue, cost, and profitability.
- *Personnel*: staff-related indicators, such as personnel training, R&D personnel, quality, and productivity.
- *Process*: various indicators related to production or delivery, such as product development time, capability, and improved ways of performing tasks.
- *Management*: organisational aspects of the company, such as strategy, policies and practices, management systems, conditions for organisational activities, certification, audits, and monitoring and control systems.
- *Product*: indicators related to the company's output, namely products such as new products or improved products.
- *Service*: indicators related to the company's output, namely services such as new services or improved services.
- *Patent*: indicators related to output, separated due to popularity in innovation research.
- *Market*: market-related indicators, such as market share, competition, demand, green markets, and new markets.
- *Cooperation*: indicators reflecting the company's activities with counterparties, such as suppliers and other stakeholders.
- *Pollution*: indicators related to pollution caused by product production, such as industrial waste recycling, carbon emissions, and sewage discharge.
- *Regulations*: it groups indicators related to governmental regulations, such as government support, incentives, subsidies, and environmental taxes.
- *Dummy*: output-related category distinguishing innovation measured directly using a dummy variable (e.g., adopted or not adopted).
- *Ordinal*: output-related category distinguishing innovation measured directly using an ordinal variable (e.g., based on the number of realised company improvements or innovations).

These 16 categories can be grouped into four clusters:

- *Direct* indicators focus on whether a certain innovation has taken place, measured as a binary or ordinal variable;
- *Output* indicators represent products, services, and patents;
- *Internal* indicators cover material and non-material resources and processes required to achieve the output (i.e., materials, natural resources, technology, finance, personnel, processes, and management);
- *External* indicators encompass external processes and stakeholders involved in or with the potential to impact the creation of the output (i.e., market, cooperation, pollution, and regulations).

The relationship between categories and clusters is presented in Fig. 2.

Measurement of different types of innovation

This chapter presents indicators used to measure the nine types of innovation mentioned in the Methodology section.

Product innovation

Product innovation has been defined and operationalised in various ways in the literature. Some researchers define it as developing and introducing new products (Markovic & Bagherzadeh, 2018), while others describe it as improving existing outcomes or continually creating new product lines. Chupina et al. (2023) define it as a product with superior technical characteristics and consumer properties, oriented to meet both current and future needs at a high level. Product innovation gives firms a competitive advantage, with a better market position, by introducing higher-quality or cost-saving products, which helps firms fill demand gaps (Galindo & Méndez, 2014) and expand market share (Leskovar-Spacapan & Bastic, 2007).

Measuring product innovation requires evaluating the introduction and impact of new or significantly improved goods or services. This assessment typically relies on traditional input-oriented indicators, such as R&D metrics. Some studies employ indicators such as total turnover sales, emphasising revenue generated from innovative products. Others focus on indicators that measure product innovation capacity. Predominantly, production innovation is measured as a dummy variable in survey-based studies. Additionally, a significant portion of research incorporates measures specifically related to new products, providing a comprehensive view of the innovation process and its results. The summary of product innovation indicators is provided in Fig. 3 and Appendix A.

Process innovation

Process innovation involves new production methods, including commercially handling goods or services. It changes manufacturing processes without altering product structure (Arfaoui et al., 2023). Lugovoi et al. (2022) notice that, while process innovation differs in nature from product innovation, researchers frequently fail to

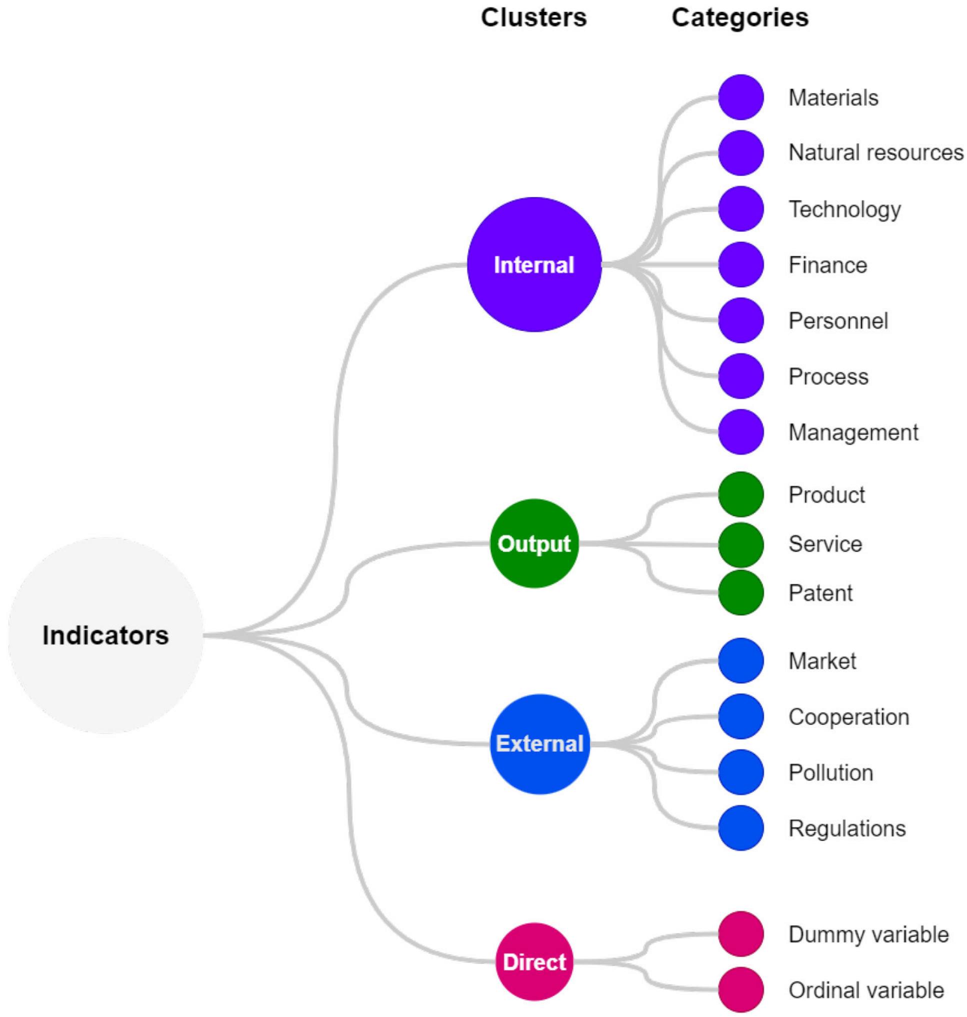

Fig. 2. Categories and clusters of innovation indicators.

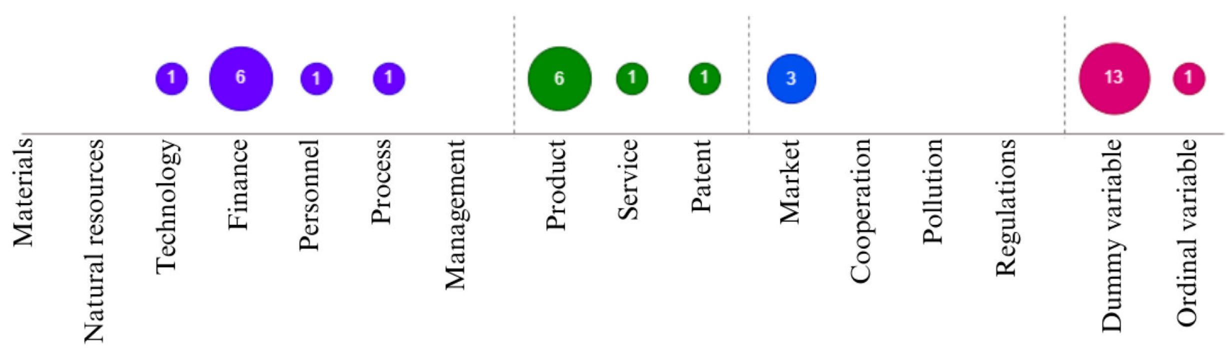

Fig. 3. Clusters and categories of indicators used to measure product innovation.

distinguish between the two. This oversight disregards the fact that the knowledge necessary for enabling process innovations is often more complex and tacit. Given that process innovations can have cross-functional impacts, their development requires input from the various functions within an organisation whose operations will be affected by the new technology.

Research on process innovation primarily uses output measures, where most studies directly ask if firms have introduced any process innovations, with results analysed as a binary variable (see Appendix A). Consequently, much of the research relies on subjective measures of process innovativeness. However, slight variations exist in the question formulation. In most studies (Altuzarra, 2017; Antonioli et al., 2021; Ayllón & Radicic, 2019), the dummy variable takes a value of 1 if a firm confirmed having introduced at least one process innovation (usually within the previous 3 years), and 0 otherwise. Other studies (Arif et al., 2020; Iandolo & Ferragina, 2021; René Wintjes, 2019) extend the question to include not only the introduction but also improvements to the processes (e.g., 'Has this firm introduced a new or significantly improved process during the last three years?'). However, these may lack clarity in defining process innovation, leading to varied interpretations by respondents.

Arfaoui et al. (2023) specify the question as: 'Has your company introduced any significant new or improved features to your manufacturing or production processes for goods or services?'. Bartelsman et al. (2019) define process innovations as the implementation of new or significantly improved production processes, distribution methods, or support activities for the firm's goods or services. Other research focuses on the new method of production (e.g., 'if the firm introduced a new method of production the previous year' (Aslam et al., 2023)) or products or services (Hussen & Çokgezen, 2020). Similarly, Aghazada and Ashyrov (2022) follow the guidelines of the OSLO Manual, asking if the company introduced any new or significantly improved methods for producing or supplying products or services within the last 3 years. Oudgou (2021) uses an even more comprehensive formulation from the World Bank's Business Enterprise Survey (WBES), asking: 'Has this establishment introduced any new or significantly improved process (including methods of manufacturing products or offering services, logistics, delivery, or distribution methods for inputs, products, or services, or supporting activities for processes)'.

Pålsson and Hellström (2023) analyse process innovation within packaging innovation, defining it as the introduction of new methods of producing packaging. This process can be broken down into three sub-processes: identifying innovations in packaging manufacturing processes, implementing new packaging manufacturing processes, and continuous improvement. These sub-processes are rated on a 4-point scale based on the extent to which they meet various requirements, ranging from bad practice through mediocre practice and good practice to best practice. Shiri et al. (2015) also count the number of innovations and also use an ordinal variable (from 0 to 4) to measure process innovation.

The study by Lugovoi et al. (2022) is the only research utilising subjective measures, analysing pharmaceutical firms' innovative output through manufacturing process patents. Systematised information regarding process innovation measurement is provided in Fig. 4 and Appendix A.

Service innovation

Due to the various forms of innovation, there is no exact definition of service innovation, which may vary across the investigated sectors. Innovation in services is more multidimensional than innovation in manufacturing. Jong et al. (2003) argue that product and process innovations usually coincide due to the simultaneity of services, meaning service innovation may encompass both product and process innovation. Aas and Pedersen (2011) further argue that nearly all innovation activities in service firms can be broadly considered service innovations and that all innovation types reported in the Community Innovation Survey (CIS) (i.e., product, process, organisational, and marketing innovation) may qualify as service innovations in service industries. However, for firms in the manufacturing industry, only new services, new logistics, delivery or distribution methods, and new product placement or sales channels can be considered service innovations (Aas & Pedersen, 2011). Public service innovation, focusing primarily on social welfare, is defined as the creation and implementation of new processes, products, services, and delivery methods, or their discontinuity, involving the participation of organisations, suppliers, and clients (Corona-Treviño, 2023).

Gotsch and Hipp (2012) argue that all service innovations can be protected with trademarks, making trademarks a measure of service (and other types of) innovation. However, most researchers utilise a set of indicators to measure service innovation. Yang et al. (2018) propose a four-dimensional model consisting of a new service delivery system, new client interface, new service concept, and technology choice, measured across 15 criteria (four criteria for each dimension, except for technology selection, which has three dimensions). Other research (Yang et al., 2010) analyses seven indicators to evaluate innovation sources. Two of these are internal quantitative indicators: the percentage of R&D funds relative to the firm's sales and the percentage of employees with at least a bachelor's degree, representing workforce quality. External innovation sources (strategic alliances, suppliers, customers, consultancy firms, and competitors) are scored from 0 to 1 based on the frequency with which firms interact with external resources, with 1 as the highest score. Kitsios and Grigoroudis (2020) analyse 24 innovation drivers, categorised into six main groups: enterprise behaviour for service innovation, idea generation sources for the provided service, actions for developing the provided service, organisational structure impact, enterprise resource allocation impact, and market impact.

Panfiluk and Szymańska (2017) offer a set of 12 measures for measuring innovativeness, including five measures for innovation actions and seven for assessing the innovative actions taken. Measurement of enterprise involvement in innovative activities includes formulating development strategies that incorporate innovations, expenditure on R&D, designated budgets for innovations, financial resources for training recalculated per employee annually, and the establishment of units responsible for the collection of market information. The assessment of the effects of innovative activities includes higher employee productivity, lower service provision costs, trade name or trademark registrations, increased service sale revenues, the limitation of tourism seasonality, and increased tourist visits in a given area annually.

Manohar et al. (2021, 2023) summarise service innovation measures, noting that researchers employ diverse, dynamic measurement scales based on various approaches. This variation in approach underscores the need for a scale for perceived service innovation, following the synthesis approach. Manohar et al. (2021) developed and tested a scale containing seven major typologies measuring service innovation, including both technological innovation (core product, peripheral product, core process, and peripheral process innovation) and non-technological innovation (organisation, strategic, and marketing innovation) components. Later, Manohar et al. (2023) developed a 22-item scale, INNOSERV, with the same seven major typologies measuring service innovation.

Unlike products, services are less standardised, and traditional R&D approaches are less applicable to service innovations. Therefore, the focus is shifting toward actual capabilities and competencies that allow firms to source ideas and convert them into marketable service

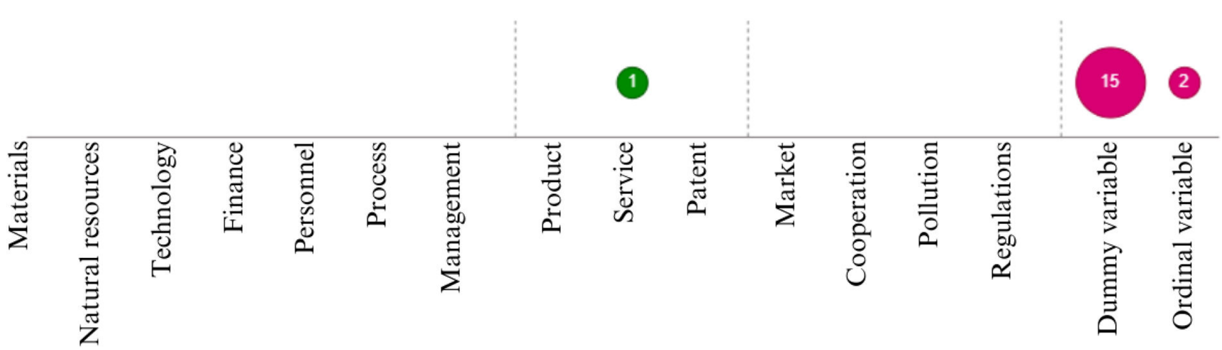

Fig. 4. Clusters and categories of indicators used to measure process innovation.

propositions (Janssen et al., 2016). Janssen et al. (2016) provide a set of dynamic service innovation capabilities in four constructs: sensing user needs and (technological) options (six items), conceptualising (four items), coproducing and orchestrating (3 items), and scaling and stretching (5 items). Babaei and Aghdassi (2022) add that dynamic service innovation capabilities (DSICs) and organisational service innovation competencies (OSICs) are critical factors in service innovation quality. They propose a framework based on the maturity model concept to measure service innovation performance and continuously improve service innovation quality. Using a specific questionnaire consisting of 34 questions, four types of firm performance in service innovation can be recognised: incapable, struggling, truncated, and exhaustive.

In Corona-Treviño's (2023) research, innovativeness is measured through the INDICO index (innovation, diffusion, co-value), adapted from technology firms. This index considers a metric of seven related innovation parameters concerning capacities and results, including the innovation selected, adaptations and replicas (possible outcomes), impacts on public and/or user values (resources and interests), knowledge depth required for the innovation's creation, implementation and delivery, design capabilities (R&D), co-value (collaboration (entailment) as co-creation and co-production (including its delivery)), and educational degrees at the innovation's beginning as well as training during the innovation's creation. The summary of service innovation indicators is provided in Fig. 5 and Appendix A.

Technological innovation

Technological innovation is usually defined as the development of new products and processes or as substantial technological improvements in existing products and processes. It presents potential profit opportunities for entrepreneurs to grasp the market; to gain more profits, enterprises need to reorganise production conditions and factors and establish a new system for production and operation that enhances efficiency and reduces costs (Chen & Zhao, 2012). The significance of technological innovation is closely associated with various aspects of firm performance and competitiveness. Research has shown that technological innovation impacts firm competitiveness (Aldianto et al., 2021; Chatzoglou & Chatzoudes, 2018), sustainable growth (Brandão Santana et al., 2015; Lee & Lee, 2021; Li & Yang, 2022), firm growth (Lin et al., 2020; Martínez-Alonso et al., 2020), and business strategies (Verbano & Crema, 2016). It is also closely linked to both process and product innovations (Geldes et al., 2017; Wu & Liu, 2016).

Most papers predominantly focus on evaluating technological innovation, while only a few have examined measurement dimensions through the lens of technological innovation efficiency (four papers) or technological innovation capabilities (two papers). Measuring technological innovation is complex and currently lacks a universally accepted framework. Some research relies on indirect indicators such as R&D expenditure and patent data (Chen et al., 2024, 2021; Gu et al., 2018; Lee & Lee, 2021; Verbano & Crema, 2016; Zhang, 2015) while others utilise direct indicators such as innovation counts and company-based surveys (Cruz-Cázares et al., 2013; Lee & You, 2016; Verbano & Crema, 2016; Yi et al., 2021; Zhang, 2015).

Technological innovations are achieved through a long and complex process involving phases such as searching, selecting, implementing, and capturing value (Cruz-Cázares et al., 2013). Although measuring technological innovations is well-established in the literature, empirical evidence remains limited. Various studies have applied technological innovation measurement at the firm level, with notable analyses conducted in countries such as China, Japan, and Spain. These studies often diverge in their methodologies: some include inputs and outputs beyond the technological innovation process (Zhang, 2022), while others associate technological innovation with direct input indicators and evaluate the final output traditionally, such as through patents or new product development. The summary of technological innovation indicators is provided in Fig. 6 and Appendix A.

Management innovation

This subsection attributes papers that study management innovation, managerial innovation, organisational innovation, and administrative innovation. Damanpour (2014) defines management innovation as 'the development and use of new approaches for performing the work of management, new organisational strategy and structure, and new processes that produce changes in the organisation's managerial procedures and administrative systems'. The Oslo Manual suggests that administration and management innovation are part of business process innovation (Oslo Manual, 2018).

Management innovation is measured by assessing inputs and outputs associated with such innovation. Input-related measures of management innovation include measures such as investment, resources organisation of management innovation (Huang et al., 2015), percentage of management staff, percentage of technical staff, percentage of sales staff, management input ratio, and R&D input ratio (Cheng et al., 2024). Management innovation is also measured by evaluating employees, including strategic and behavioural innovativeness for all levels of managers (Ghosh & Srivastava, 2022), the extent of creativity, openness to change, future orientation, risk-taking, and proactiveness (Raj & Srivastava, 2016). Output-related indicators include regularly renewed rules and procedures, regular changes to the employees' tasks and functions, the regular implementation of new management systems, changes in policy compensation, regular restructuring of intra- and inter-departmental communication structures, and continuous alterations of organisational structure (Hassi, 2019). Heyden et al. (2018) measure management innovation by looking for indications of changes in how organisations arrange communication and align and harness effort from their members, changes in routines that govern the work of managers, and changes in what managers do as part of their job on a day-to-day basis. Giotopoulos et al. (2017) track the number of improvements or innovations realised in the firm's functions during the last 3 years. Finally, Li et al. (2014) evaluate management innovation

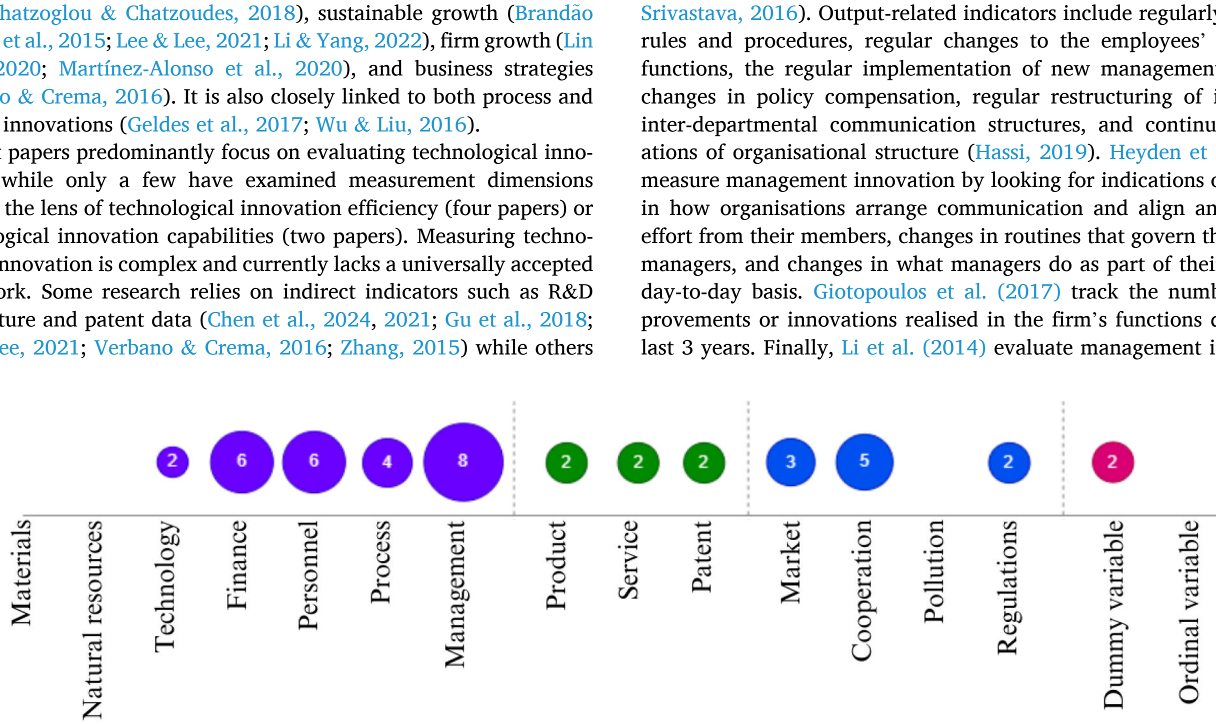

Fig. 5. Clusters and categories of indicators used to measure service innovation.

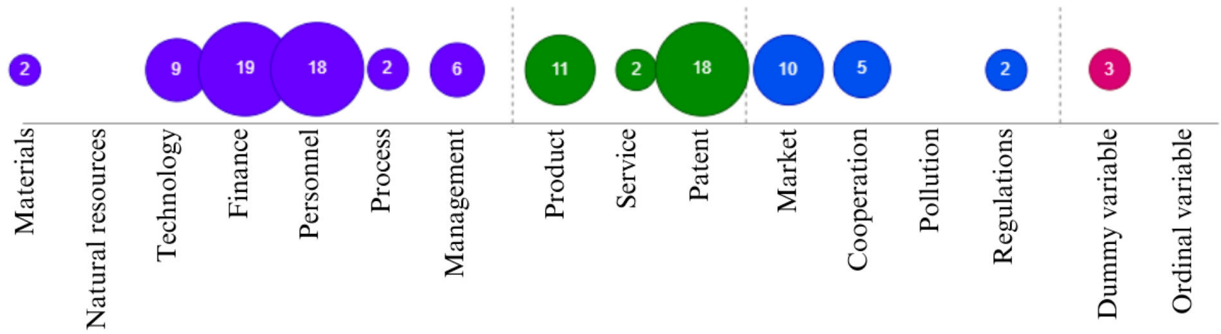

Fig. 6. Clusters and categories of indicators used to measure technological innovation.

based on the extent of employee development and safety, operations effectiveness, the market, and the financial and social influence of the organisation. Scholars (Ghosh & Srivastava, 2022; Giotopoulos et al., 2017; Hassi, 2019; Li et al., 2014; Raj & Srivastava, 2016) primarily rely on surveys to measure management innovation. Heyden et al. (2018) combined reports from an HR consulting firm that conducts performance evaluations of managers with companies' archival sources to measure the extent of management innovation as a function of keywords related to changes in communication structures, organisational routines, and managers' day-to-day activities.

While scholars suggest that management innovation, managerial innovation, organisational innovation, and administrative innovation have considerable overlap (Damanpour, 2014; Henao-García & Cardona Montoya, 2023; Walker et al., 2015), this analysis reveals a stark divergence in the measurement of organisational and management (including managerial and administrative) innovation. Authors measuring organisational innovation (Cheng et al., 2024; Ghosh & Srivastava, 2022; Raj & Srivastava, 2016) tend to focus on measures of organisational innovation capacity or company innovativeness. Conversely, authors concentrating on measuring management innovation focus on managers' efforts to introduce new structures, processes, systems, programs, or practices within an organisation or its units (Walker et al., 2015). However, measures vary extensively within these two categories, underscoring the need for convergence, as it may affect comparability and hinder the accumulation of evidence regarding the antecedents and effects of management innovation. The summary of management innovation indicators is provided in Fig. 7 and Appendix A.

Business model innovation

Business models are structural templates for how firms run and develop their businesses on holistic and systemic levels (Clauss, 2017). This study draws on Foss and Saebi's definition of business model innovation as 'designed, novel, and nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements', understanding business model innovation in terms of novelty and scope (Foss & Saebi, 2017).

Business model innovation is measured by measuring the outputs associated with such innovation. Several strategies are associated with the measurement of business model innovation. First, scholars measure business model innovation directly by probing for changes to the business model or parts of the business model (Bouwman et al., 2019; Liu et al., 2024). Measures include various types of business model change, such as changing the entire business model, changing only some components of the business model, changing the product or service offering before changing the business model, changing the business model before changing the product or service offering, making simultaneous changes to the business model and product or service offering, and trying out new business models in practice before making final changes (Bouwman et al., 2019).

The second measurement approach for business model innovation assumes that it can be aggregated into three dimensions: value creation, value proposition, or value capture (Breier et al., 2021; Clauss, 2017; Spieth & Schneider, 2016). Accordingly, scholars directly measure the change in value creation (Breier et al., 2021), change in value proposition (Breier et al., 2021; Ciampi et al., 2021; Niyawanont, 2023), and change in value capture (Breier et al., 2021) to gain insights into the scope and extent of business model innovation.

Finally, the third measurement approach operationalises these three business model dimensions and consecutively measures the changes within these dimensions (Clauss, 2017). To measure the scope and extent of change in the value creation dimension, scholars measure the extent of change in competencies and resources (Clauss, 2017; Hock-Doepgen et al., 2021; Müller et al., 2018; Spieth & Schneider, 2016), technology or equipment (Clauss, 2017; Hock-Doepgen et al., 2021; Müller et al., 2018; Spieth & Schneider, 2016), processes and structures (Ciampi et al., 2021; Clauss, 2017; Hock-Doepgen et al., 2021; Spieth & Schneider, 2016), and partnerships (Ciampi et al., 2021; Clauss, 2017; Hock-Doepgen et al., 2021; Liu et al., 2024; Müller et al., 2018; Niyawanont, 2023; Spieth & Schneider, 2016). To measure the scope and extent of change in the value proposition, researchers probe for changes in customers and markets (Ciampi et al., 2021; Clauss, 2017;

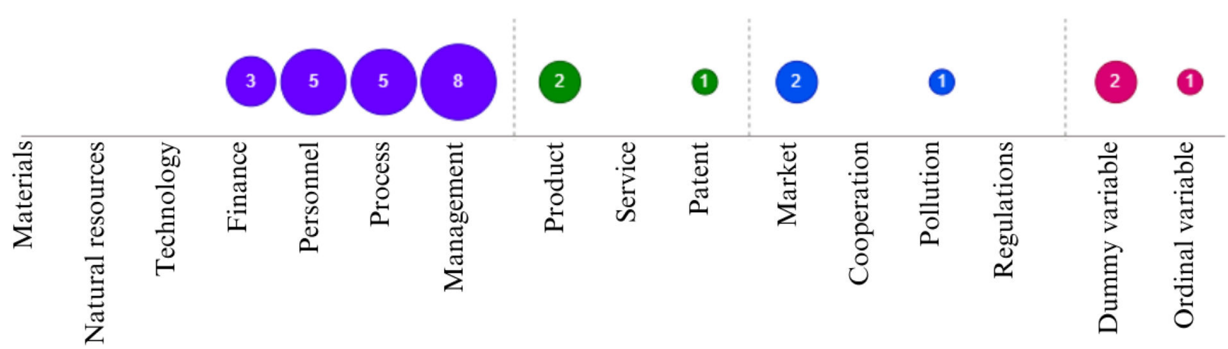

Fig. 7. Clusters and categories of indicators used to measure management innovation.

Hock-Doepgen et al., 2021; Müller et al., 2018; Spieth & Schneider, 2016), firms' offerings (Clauss, 2017; Hock-Doepgen et al., 2021; Liu et al., 2024; Müller et al., 2018; Niyawanont, 2023; Spieth & Schneider, 2016), channels (Clauss, 2017; Hock-Doepgen et al., 2021), and customer relationships (Clauss, 2017; Liu et al., 2024). Finally, to measure changes in value capture innovation, scholars track changes in revenue models (Ciampi et al., 2021; Clauss, 2017; Hock-Doepgen et al., 2021; Liu et al., 2024; Müller et al., 2018; Spieth & Schneider, 2016) and cost structures (Clauss, 2017; Hock-Doepgen et al., 2021; Spieth & Schneider, 2016). Accordingly, a comprehensive picture of business model innovation can be obtained.

In summary, output-based metrics dominate the measurement of business model innovation, focusing primarily on the direct measurement of changes to business models and their components. The most detailed approach operationalises these components, enabling the capture of business model innovation at a granular level. The summary of business model innovation indicators is provided in Fig. 8 and Appendix A.

Supply chain innovation

Supply chain innovation is defined as a multifaceted process designed to address environmental uncertainties, meet customer needs, and improve organisational processes through the adoption of new technologies. This innovation can involve incremental or radical changes within the supply chain network, technology, or processes. It can occur at various levels, including individual company functions, entire companies, industries, or the broader supply chain, with the primary goal of creating new value for stakeholders (Abdallah et al., 2021; Arlbjørn et al., 2011; Lee et al., 2011). Therefore, supply chain innovation involves sharing skills, expertise, and resources among key supply chain partners. This collaboration is essential, as a single firm may not possess all the required resources and capabilities for the innovation process (Iddris, 2016; Ojha et al., 2016).

Despite the growing interest in supply chain innovation, only a few studies have examined how to measure it, and no standardised indicators for measuring it exist. Wong and Ngai (2022) developed a supply chain innovation model, defining and conceptualising its constructs and presenting a 31-item instrument for supply chain innovation. Three categories of innovation activities were identified: marketing-oriented, technological-development-oriented, and logistics-oriented innovation activities, each encompassing different areas of focus. Chan et al. (2014) analyse innovation using R&D and sales of products and services, while Calabrese et al. (2024) also incorporate R&D investments to assess the innovation process. Most studies emphasise indicators related to staff and cooperation with customers and suppliers. The summary of supply chain innovation indicators is provided in Fig. 9 and Appendix A.

Green innovation

This sub-section summarises articles that consider green, environmental, or eco-innovation in enterprises, with these terms used interchangeably. Green innovation primarily refers to innovation activities aimed at promoting the development of green technologies, such as energy conservation, emissions reduction, clean production, and the use of renewable energy. Compared to other innovation activities, green innovation is not only capital intensive but also associated with high levels of risk and characterised by long cycles. It also requires stable, long-term financial support for enterprises to engage in green innovation activities (Li & Shen, 2022).

Eco-innovation, as defined by Ghisetti and Pontoni (2015), involves 'the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the firm or organisation and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives'. This includes innovations that are not necessarily new to the world but are at least new to the organisation adopting them, as outlined in the Oslo Manual, hence new environmental technologies and any new/-improved products, processes, or services must be accounted for. Furthermore, this also includes 'unintended' innovations that result in environmental improvements.

Munodawafa and Johl (2022) analyse eco-innovation capabilities and define them as product–service stewardship, environmental pollution prevention, and a commitment to sustainable development— antecedents that enable firms to achieve sustained competitive advantages by pre-empting competitors, reducing costs, and enhancing future positioning. Eco-innovation might cover different (and multiple) environmental domains (Ghisetti & Pontoni, 2015). The Community Innovation Survey (2006–2008) differentiates 9 typologies of eco-innovation depending on the domain covered, i.e. whether the environmental benefits arise during the production process (reduced material, energy, CO2, soil, water, noise, or air pollution, replaced materials with less polluting or hazardous substitutes, recycled waste, water, or materials) or after use (end-user benefits, related to reduced energy use, air, water, soil or noise pollution, improved recycling of product after use).

García-Granero et al. (2018) provide a literature review on eco-innovation performance indicators based on the analysis of 104 publications from January 1990 to December 2017. The study identifies 30 frequently cited firm performance indicators and classifies them into four green innovation categories: product, process, organisational, and marketing. This research updated previous reviews with the newest publications and highlights diverse measures.

According to Kiefer et al. (2017), a common understanding of eco-innovation characteristics is lacking, suggesting that eco-innovations are characterised not solely by their environmental impacts but also by a combination of characteristics across the four dimensions of design, user, product-service, and governance. The design

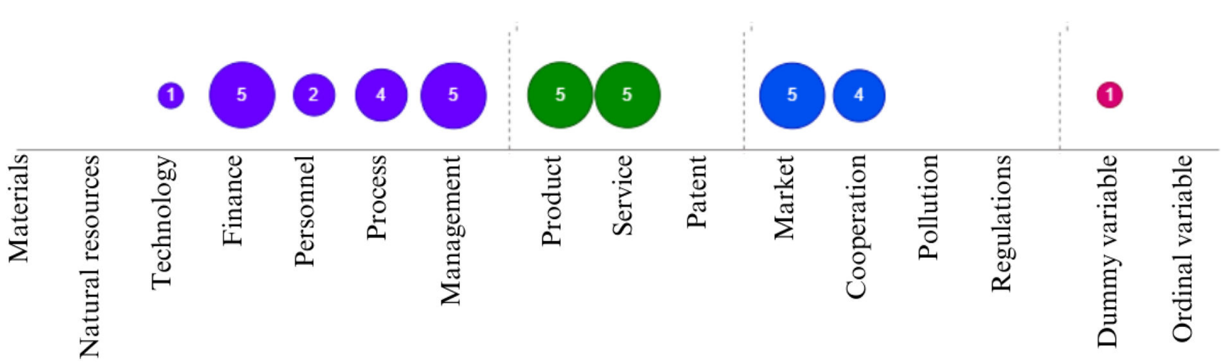

Fig. 8. Clusters and categories of indicators used to measure business model innovation.

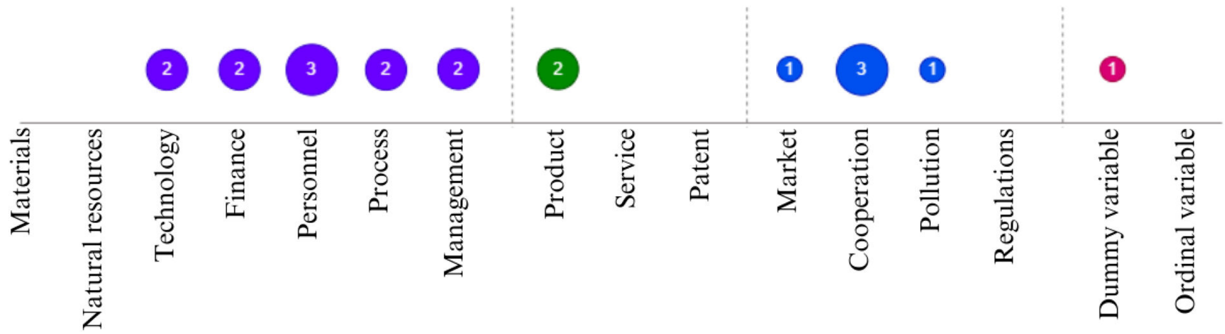

Fig. 9. Clusters and categories of indicators used to measure supply chain innovation.

dimension stresses the impact of eco-innovation on processes, products, and organisational changes, particularly the reduction of inputs (such as materials, energy, and water) and outputs (emissions). Research by Kiefer et al. (2017) underscores the critical role of user and client engagement, acceptance, and cooperation with other stakeholders in the eco-innovation process.

It can be noticed that the categories of green innovation and the number of analysed categories vary between studies. According to Rashid et al. (2014), there are five types of eco-innovation predominant for sustainable development: product, process, institutional, marketing, and organisational. Meanwhile, Amores-Salvadó et al. (2015) focus solely on green product innovations, while others (Jiang et al., 2021; Wang, 2022; Yin et al., 2020) analyse green technology innovation. Yin et al. (2020) created an evaluation system for green technology innovation capability, considering four aspects: input elements, technology output, economic output, and social effect. Su et al. (2024) used different dimensions for the same purpose: innovation investment capability, green technology R&D capability, green technology supporting capability, and green technology output capability. Ahmed et al. (2023) measured green innovation using two dimensions: product and process. The synthesis of the eco-process indicators in the context of manufacturing firms was conducted by Mat Dahan and Yusof (2020) through a systematic literature review based on 45 papers published until July 2017, grouped into economic, social, and environmental categories. Studies by Dang et al. (2024) and Maldonado-Guzmán et al. (2020) encompass green product, process, and management innovations, while García-Pozo et al. (2018) consider product, process, or organisational innovation. Biscione et al. (2021) also consider three types of eco-innovations: eco-innovative goods or services, eco-innovative production processes or methods, and eco-innovative organisational change. Li et al. (2022) analyse four core dimensions of green innovation: technological, product, institutional, and environmental. The study by García-Granero et al. (2020) offers a multidimensional eco-innovation measurement and confirms the importance of product, marketing, organisation, and process.

Other researchers do not specify particular types of innovation and instead utilise general indicators (e.g., R&D expenditure) or specific indicators that may relate to certain types of innovation. For example, when measuring eco-innovation, Marín-Vinuesa et al. (2020) consider financial resources, including the amount and types, technology and environmental management capabilities, and other variables such as the organisation's age and size. Asiaei et al. (2023) measure ambidextrous green innovation using a scale comprising eight items, with four for exploitative green innovation and four for exploratory green innovation.

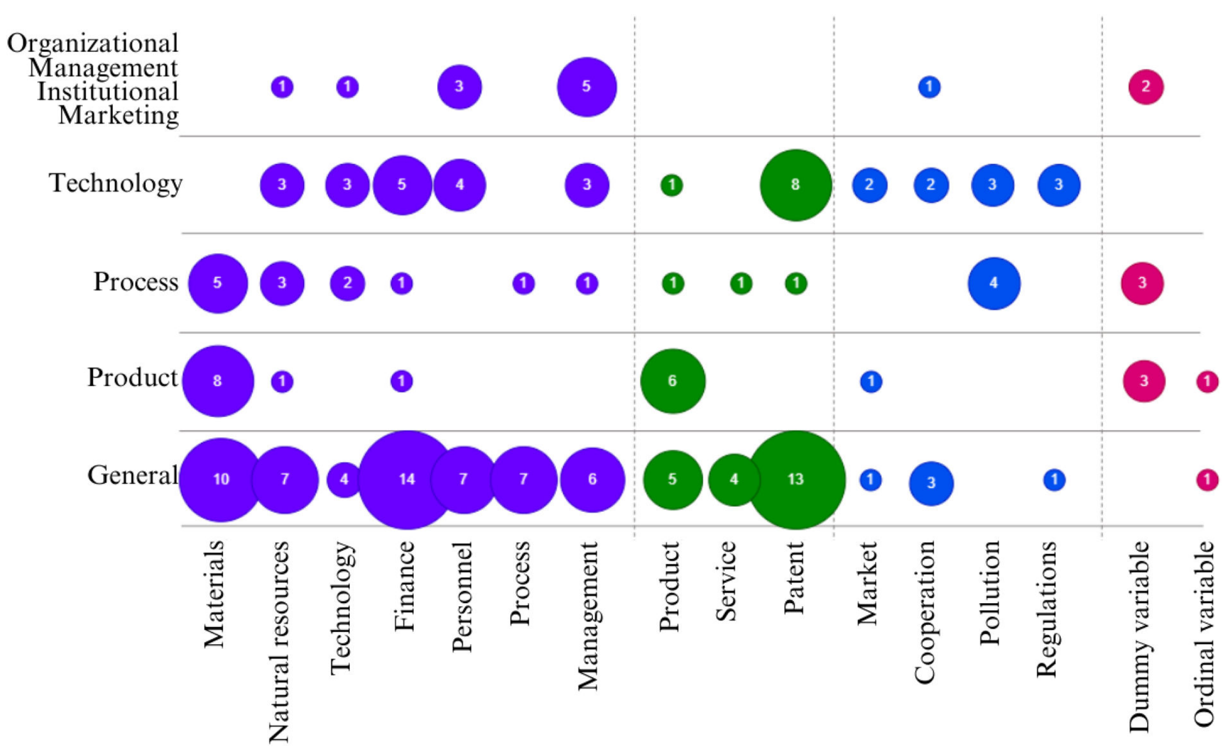

Fig. 10. Clusters and categories of indicators used to measure green innovation.

The summary of indicators used to measure green innovation is provided in Fig. 10 and Appendix A.

Open innovation

Open innovation does not signify a specific innovation type. Instead, researchers argue that increased worker mobility, more capable universities, growing access of startup firms to venture capital, and the rise of the internet undercut the logic of the traditional 'closed innovation' model, where a company relies solely on its internal resources, knowledge, and capabilities to develop new products and technologies (Chesbrough, 2003). Instead, an open innovation model, 'that emphasises purposive inflows and outflows of knowledge across the boundary of a firm to leverage external sources of knowledge and commercialisation paths' (Chesbrough & Bogers, 2014), has been proposed. Open innovation thus captures a shift in the innovation process, whereby companies create mechanisms allowing for greater use of external ideas and technologies in their own business, as well as allowing unused internal ideas and technologies to flow outside for others to utilise (Chesbrough & Bogers, 2014).

Open innovation is measured through inputs, processes, and outputs. Few authors have used input-oriented measures for open innovation. Michelino et al. (2014) and Michelino et al. (2015) measure the extent of open innovation through the costs of collaborative development, outsourcing of R&D services, in-licensing costs, and additions of innovation-related intangibles. Most studies use activity-based measures (Aftab Alam et al., 2022; Al-Belushi et al., 2018; Bae & Chang, 2012; Bellantuono et al., 2021; Lu & Chesbrough, 2022). Scholars seek to empirically capture the Outside-In (or Inbound), Inside-Out (or Outbound), and Coupled open innovation mechanisms by measuring related firm activities. For example, Cheng and Huizingh (2014), Costa et al. (2021), and Lima Rua et al. (2023) measure the extent of Outside-In activities through the direct involvement of external parties in innovation projects, innovation projects' dependence on external party contribution, purchase of R&D services and intellectual property from external parties, and investment in other firms. Inside-out activities are measured through the extent of selling intellectual property, offering royalty agreements to other firms, strengthening the use of intellectual properties, and spin-offs to better benefit from innovation efforts. Finally, Coupled open innovation activities are captured by measuring the extent of companies' integration of internal and external partner information, coordination of information exchange among partners, and keeping internal and external partners updated on innovation projects. Often, authors concentrate on a single open innovation, such as Outside-In (Al-Belushi et al., 2018; Marullo et al., 2022). The most prevalent approach to measuring the extent of Outside-In activities is through assessing the breadth of the extent to which firms draw on different external knowledge sources for innovation, as well as the depth of the extent to which they draw intensively on external knowledge sources (Marullo et al., 2022). Finally, other authors indiscriminately consider open innovation mechanisms while measuring varied activities to capture the extent of firms' open innovation, such as network and community engagement, customer engagement, partnership and joint venture activities, industry–academia collaboration, contracts and IP licensing, and bilateral transactional activities (Lu & Chesbrough, 2022).

Few attempts to measure open innovation are based on output-related indicators. Barge-Gil (2013) identifies semi-open, open, and ultra-open firms based on the extent of collaboration during product innovation. Semi-open firms cooperate or buy external R&D but primarily generate product innovations internally. Open firms produce product innovations mainly through joint efforts with other entities. Finally, ultra-open firms generate product innovations mainly through third parties. Al-Belushi et al. (2018) use products, services, or process innovation introduction items, together with item probing, to capture additional value, as new products and services jointly developed by the firm have opened up new market opportunities and expanded the company's customer base. Michelino et al. (2014) and Michelino et al. (2015) measure open innovation through revenues from collaborative development, revenues from R&D services on behalf of third parties, revenues from out-licensing, and disposals of innovation-related intangibles. The summary of indicators used to measure green innovation is provided in Fig. 11 and Appendix A.

Comparison of measurement of different types of innovation

The growing popularity of innovation measurement among researchers highlights the relevance and complexities of this topic. However, this trend is largely related to the increased attention to green (eco, environmental) innovation, which has seen rapid research growth since the beginning of this decade (Fig. 12), reflecting heightened concern about climate change issues and a focus on implementing environmental policies. Technological innovation is the next most popular type of innovation in research, though it is discussed only half as frequently as green innovation; this focus is driven by the digitalisation and automation of company processes.

Concerning innovation indicators, internal indicators are predominant in research. Financial indicators are the most popular, observed in 40 % of all the studies (Table 1), with R&D expenditure as the most common among them. Income, sales, cost, and profit-related indicators are also widely used. Staff-related indicators are observed in one-third of the research, covering factors such as the number of R&D personnel, highly skilled employees, staff satisfaction, staff quality, and training. Every fourth study incorporates management (organisational, administrative) indicators to measure innovation, covering aspects such as a company's strategy, marketing innovation, organisational structure, firm regulatory framework, and organisational coordination ability. The same proportion of papers uses patent data as an output indicator and a direct measure of innovation, asking whether a particular innovation has occurred and expressing it as a dummy variable.

The analysis results indicate no specific indicators for a particular type of innovation. However, several aspects should be noted. First, indicators related to materials, natural resources, and pollution appear predominantly in green innovation research, while these are rarely considered when measuring other types of innovation. Macro-environmental and governmental indicators are also seldom utilised across research types.

Second, investigating a specific type of innovation does not imply that only indicators closely related to that type are considered. Typically, a broader perspective dominates. Table 1 shows that for service innovation, only 14 % of studies (2 out of 14) employ service-related indicators, while management, finance, and personnel-related indicators are more commonly utilised. Technology-related indicators appear in one-third of studies for technological innovation, while finance, personnel-related indicators, and patents are more frequently highlighted. Consequently, questions arise regarding whether these indicators reflect the specificity of a particular innovation and if such measurement approaches are appropriate.

Research on process innovation stands out by specifically using direct measures, excluding other indicators. Management innovation focuses on management-related indicators, which appear in 62 % of related studies. Product-related indicators are as important as financial indicators in product innovation measurement, though direct measures are twice as prevalent.

Data sources

Table 2 provides information on the data sources used for measuring innovation types. Quantitative surveys, including both primary and established, are the most prevalent approach to measuring innovation. Of all attempts to measure innovation, 58 % were conducted using survey data. Interviews and expert surveys accounted for an additional

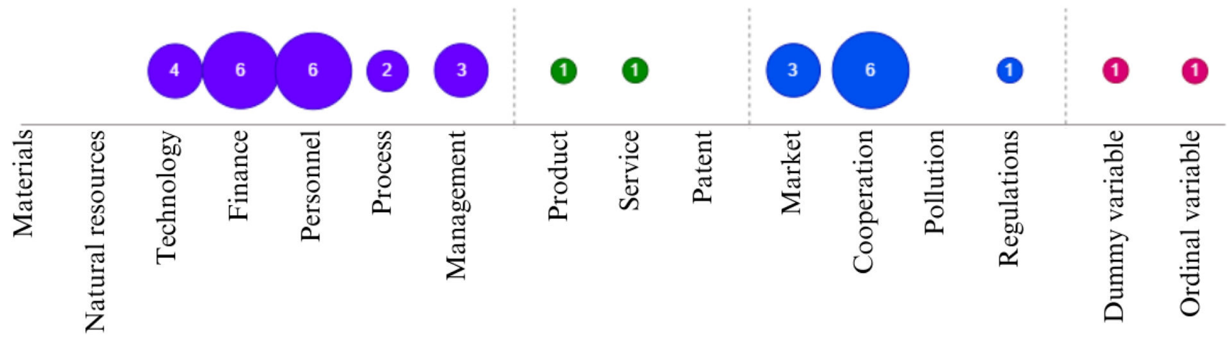

Fig. 11. Clusters and categories of indicators used to measure open innovation.

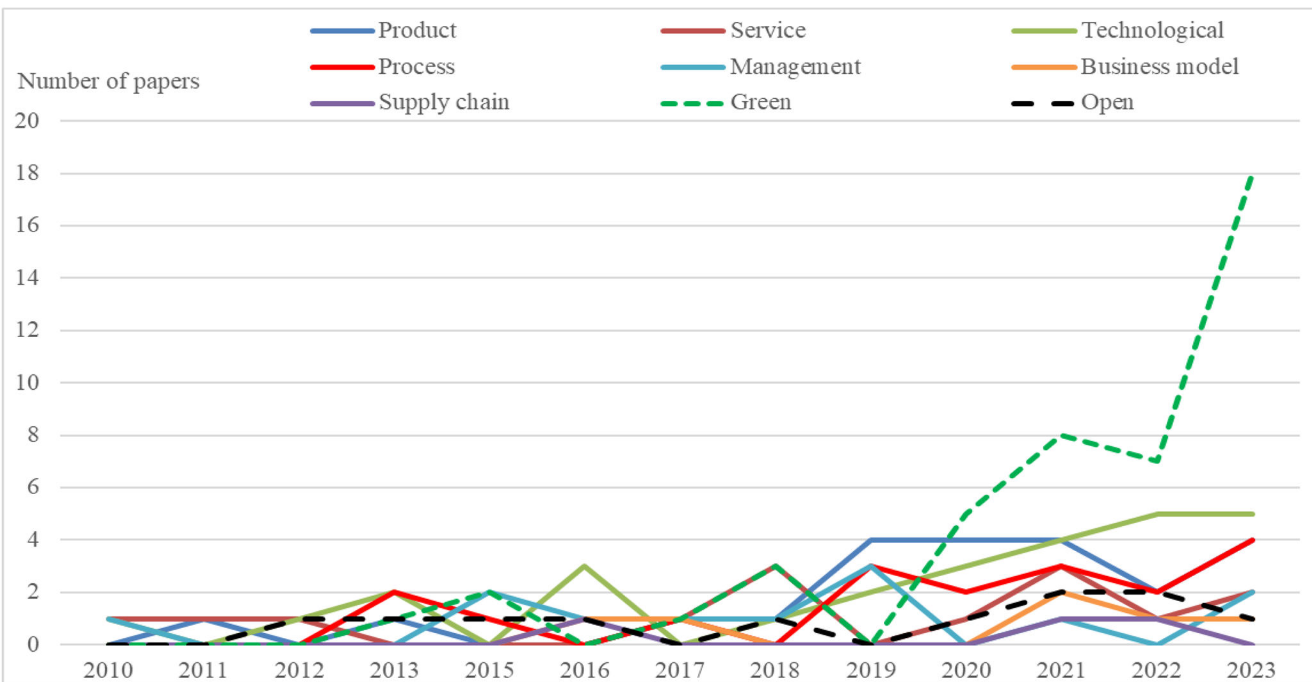

Fig. 12. Number of papers on a particular type of innovation.

11.2 % of all innovation measurement attempts. Together, these sources account for 69.1 % of innovation measurement studies. Statistical data, including data from financial and other reports of companies, industry, macroeconomic statistics, and patent data, were employed by 30.3 % of papers. Finally, only 0.5 % of papers in this dataset utilise machine learning methods to process data from company websites. In summary, scholars predominantly rely on survey data, followed by statistical data, to measure companies' innovative activities.

Analysis of data sources further reveals which data sources dominate the measurement of specific innovation types. Product (91.7 %), process (95 %), service (100 %), management (85.7 %), business model (100 %), supply chain (100 %) and open (83 %) innovation measurement relied on surveys as core data sources. Conversely, statistical data is more frequently used to measure technological (62.1 %) and green (54.2 %) innovation types. Established surveys, particularly the Community Innovation Survey (CIS), dominate in the measurement of product (54,2 %) and process (55 %) innovations. In summary, this analysis reveals that survey data dominates the measurement of most innovation types, with the exceptions of technological and green innovations, which rely more extensively on statistical data. Additionally, it reveals the low prevalence of big data sources, such as companies' websites, social media, online reviews, and feedback data for innovation measurement. Survey data tends to be limited by incomplete sector coverage, subjectivity issues, low timeliness, and limited comparability across industries and firms while measuring innovations (Cirera & Muzi, 2020; Rammer & Es-Sadki, 2022). Furthermore, listed and larege companies which tend to patent their innovations, are overrepresented in statistical data (Hagedoorn & Cloodt, 2003). Big data sources hold promise for addressing some of these issues in innovation measurement, at least for product and service innovation measurement (Rammer & Es-Sadki, 2022).

Limitations and future research directions

Existing studies encounter several limitations in measuring innovation. Some of these limitations are common across all types of innovation, while others are specific and relevant only to certain innovation types. A prevalent challenge in most studies is the availability and interpretation of data. Evaluating innovation solely through patent and R&D indicators can be restrictive, as crucial innovation details may be overlooked. Additionally, companies may interpret innovation evaluation results differently due to varying definitions of innovation, such as focusing exclusively on new-to-market innovations, R&D-based innovations, or product innovations. Another general limitation is the timeliness of the data, namely information used for innovation assessment may be collected long before the evaluation is conducted,

Table 1
Summary of innovation indicators.

Clusters	Categories	Product	Service	Technological	Process	Management	Business model	Supply chain	Green	Open	Percentage of all papers
Internal	Materials			2					23		**14,5%**
	Natural resources								14		**8,1%**
	Technology	1	2	9			1	2	9	4	**16,3%**
	Finance	6	6	19		3	5	2	22	6	**40,1%**
	Personnel	1	6	18		5	2	3	14	6	**32,0%**
	Process	1	4	2	0	5	4	2	8	2	**16,3%**
	Management		8	6		8	5	2	14	3	**26,7%**
Output	Product	6	2	11		2	5	2	13	1	**24,4%**
	Service	1	2	2			5		5	1	**9,3%**
	Patent	1	2	18	1	1			23		**26,7%**
External	Market	3	3	10		2	5	1	11	3	**22,1%**
	Cooperation		5	5			4	3	6	6	**16,9%**
	Pollution					1		1	7		**5,2%**
	Regulations		2	2					4	1	**5,2%**
Direct	Dummy	13	2	3	15	2	1	1	8	1	**26,7%**
	Ordinal	1			2	1			2	1	**4,1%**
Number of papers		**22**	**14**	**29**	**18**	**13**	**7**	**5**	**51**	**13**	**172**
Percentage of all papers		**12,8%**	**8,0%**	**16,7%**	**10,3%**	**7,5%**	**4,0%**	**2,9%**	**29,3%**	**7,5%**	**100%**

Table 2
Number of papers according to the data sources.

Type of data sources	Survey			Statistical databases			Company web-page
Type of innovation	Primary surveys of companies	Established innovation surveys	Interviews, expert surveys	Financial and other reports of companies	Industry, macro-economic statistics	Patent databases	
Product	8	13	1		2		
Process	6	11	2			1	
Service	8	3	6				
Technological	6	2	3	3	11	4	1
Management	7	2	3	2			
Business model	6		1				
Supply chain	3	1	1				
Green	22	3	2	6	10	16	
Open	4	4	2		2		

potentially leading to inaccuracies.

Most research on innovation relies on subjective measurements, which may compromise the accuracy of assessments. Furthermore, the varying wording of questions given to respondents can lead to confusion and complicate the comparison of results due to differing understandings and interpretations of these questions.

The abundance and variety of indicators employed to measure innovation may complicate the interpretation and comparison of different research studies and, consequently, the results of innovation assessments. Moreover, most of these measures are used fragmentarily and still require validation through empirical studies. Therefore, analysing the usefulness of each proposed measure, as well as developing a framework that aggregates and unifies the constructs used for innovation measurement, will be invaluable. Additionally, the degree of novelty and input variables often rely on subjective assessments from survey respondents, affecting accuracy.

In general, the measurement of different innovation types faces significant limitations, particularly concerning overlapping indicators. For instance, several indicators are used interchangeably to measure green product and green process innovation. One example is the green patent number, which is considered a process innovation indicator by García-Granero et al. (2020), yet is regarded as a technology innovation indicator by Elmawazini et al. (2022) and Bai and Lin (2024). A substantial gap exists in the literature regarding this issue, as studies do not encompass a comprehensive combination of key performance indicators across the different types of eco-innovation. This comprehensive information is essential for accurately measuring the level of eco-innovation and benefits companies and stakeholders in performance evaluation. Furthermore, identifying the most suitable performance indicators for measuring environmental innovation enables governments to formulate policies that encourage companies to adopt sustainable practices, allowing firms to implement green initiatives more effectively.

The utilisation of judgmental sampling in measuring innovation constrains the extent to which results can be generalised beyond the specific context of innovation, despite offering valuable insights into the phenomenon under study. However, the input variables derived from surveys or expert interviews entail inherent limitations, including the time-intensive nature of surveys and the potential for biases stemming from managers' decisions to participate or abstain, potentially resulting in the overlooking of significant observations.

Despite the rapid evolution of innovation studies over the past two decades, accelerated by heightened awareness among researchers, a significant gap remains in understanding more detailed measurement approaches and indicators. Future research should address these limitations to enhance the accuracy and utility of innovation measurement, with a more specific focus on various innovation types.

Discussion

The literature review reveals several issues related to innovation measurement. One source of confusion identified in the literature analysis on innovation measurement is the variation in definitions. Since various types of innovation are interrelated, their definitions overlap. Consequently, it becomes complicated to clearly state what types of innovation are implemented within a company, thereby confusing the selection of correct indicators for measuring different types of innovation.

The keyword 'new or improved products' dominates in most definitions of product innovation. However, new or improved services are sometimes also included in that group, even in the CIS. Meanwhile, the keywords 'new services', 'new processes', 'new products', 'new product placement or sales channels', and 'new logistics, delivery or distribution methods' can be found in the definitions of service innovation. Product innovation, process innovation, organisational innovation, and marketing innovation may also be considered service innovations according to Aas and Pedersen (2011). Process innovation is usually understood as new methods of production and new ways of commercially handling a good or a service, while technological innovation involves the development of new products and processes or substantial technological improvements in existing products and processes. Thus, it is evident that these types of innovation overlap.

Administration and management innovations are part of business process innovations. Keywords 'new approaches for performing the work of management', 'new organisational strategy and structure', and 'new processes that produce changes in the organisation's managerial procedures and administrative systems' are used to define management innovation. Thus, researchers should be careful not to mix management and process innovation. Moreover, management innovation is interrelated with business model innovation, which refers to the process of developing and implementing new ways to create, deliver, and capture value within an organisation. It is also related to supply chain innovation, which is defined as a multifaceted process aimed at addressing environmental uncertainties to meet customer needs and improve organisational processes through the adoption of new technologies. It also involves sharing skills, expertise, and resources among crucial supply chain partners, resembling the concept of open innovation (the inflows and outflows of knowledge across a firm's boundaries to leverage external sources of knowledge and commercialisation paths). For example, CIS2018 includes questions on the introduction of new methods for information processing or communication, new methods for accounting or other administrative operations, new business practices for organising procedures or external relations, new methods of organising work responsibility, decision-making, or human resource management, and new marketing methods for promotion, packaging, pricing, product placement or after-sales services. These are all grouped as questions related to process innovation. Lastly, green, environmental, or eco-innovation may encompass most, or even all, of the previously mentioned types of innovations if the innovation addresses environmental issues.

Due to the confusion in the definitions and measurement of innovation, it is strongly recommended to refine the essence of each type of innovation and select core indicators to measure it. Table 3 presents the

Table 3
The main focus of different types of innovations and clusters of related innovation indicators.

Types of innovation	Main focus	Main clusters of innovation indicators
Product	development and introduction of a new or significantly improved good, i.e. new design, functionality, features	Product
Service	development and introduction of new or significantly improved services	Service
Technological	application of new technologies or the improvement of existing technologies	Technology
Process	new or significantly improved production or delivery method, changes in workflow, procedures, resource management	Process
Management	new management practices, processes, structures, or techniques that enhance the performance (effectiveness) of an organization, changes in organizational culture, leadership styles, or administrative procedures, new ways of decision-making, performance management and evaluation, engagement practices, communication	Management
Business model	new ways to create, deliver, and capture value to customers, new customer segments, market positioning, revenue streams, pricing strategy, cost structures	Market Financial
Supply chain	flow of goods, information, and services throughout the supply chain, i.e., new ways of logistics, procurement, collaboration between suppliers, manufacturers, distributors, and customers	Cooperation (with suppliers, manufacturers, distributors, and customers)
Green	minimization of environmental harm, pollution, promotion of efficient use of resources, use of renewable resources, reduction of waste, optimization of energy use, enhancing sustainability	Materials Natural resources Pollution
Open	collaboration and knowledge sharing between organisations, individuals, and communities	Cooperation (with partners, excluding suppliers, manufacturers, distributors, and customers)

main focus of each type of innovation and the clusters of innovation indicators that best reflect it.

We suggest using the main cluster (or clusters) of innovation indicators that best represent that type of innovation, avoiding the inclusion of indicators that may represent other types of innovation. Patents serve as proof of innovation and can be used as an innovation indicator in each case but should be directly related to that type of innovation. That is, product patents can serve as innovation indicators of product innovation but not of other types of innovation. Since no process or innovation can occur without people, personnel-related indicators should be carefully selected to reflect a certain type of innovation.

While various types of innovation are indeed interrelated, separating them to avoid indicator duplication is challenging. For example, indicators reflecting technologies are not only related to technological innovations but can also be related to processes, supply chains, and other types of innovation. Technology innovation also often leads to the creation of new products or services. However, researchers should agree on common indicators for measuring different types of innovation to avoid confusion and facilitate the comparison of research results.

Thus, suggested indicators for innovation measurement are based on the primary focus and differences of each type of innovation. For example, product innovation focuses on physical goods that can be manufactured, while service innovation emphasises intangible services that provide value to customers. Management innovation involves internal organisational transformations, whereas business model innovation considers external indicators, such as the value a business offers to its customers. Supply chain innovation can be analysed through indicators of cooperation with suppliers, manufacturers, distributors, and customers, while open innovation can be measured using indicators of cooperation with universities, start-ups, associations, and companies beyond suppliers, manufacturers, distributors, and customers.

Conclusions

This paper presents a systematic literature review summarising innovation indicators according to nine types of innovation: product, process, service, technological, management (or organisational, administrative), business model, supply chain, green (or environmental, eco), and open innovation. The study indicates that green innovation, also known as environmental or eco-innovation, has emerged as the most extensively researched area in recent years. The increasing volume of research in this field reflects growing global awareness and concern over climate change and the urgent need for solutions to mitigate its effects. Green innovation encompasses a broad range of activities, including the development of new technologies, processes, and products that minimise environmental impact, thus intersecting with many other types of innovation.

Surveys, including both primary and established surveys, are the most commonly used method, accounting for 58 % of all innovation measurement efforts. Established surveys, such as the Community Innovation Survey (CIS), are especially prominent in measuring product and process innovations. Meanwhile, technological and green innovations rely more heavily on statistical data. Statistical data, such as financial reports, industry statistics, and patent data, are used in 30.3 % of cases. However, there is limited use of big data sources, such as company websites and social media, to measure innovations. Machine learning methods applied to company websites are used in only 0.5 % of studies.

This study demonstrates that definitions are a significant challenge in measuring innovation. First, scholars define each type of innovation in various ways. Second, definitions overlap due to the interrelated nature of different innovation types. Consequently, confusion arises over selecting appropriate indicators for measuring different types of innovation.

The study reveals that no particular indicators are exclusive to specific types of innovation. Instead, researchers employ a wide range of indicators, many of which are not closely tied to a particular type of innovation. Most innovation measurements focus on financial and personnel-related indicators across different types of innovation. This broad approach can limit the ability to capture the specific nature of certain innovations, leading to inaccurate assessments.

Accordingly, this paper presents recommendations for selecting innovation indicators based on their type. It includes a list of clusters of innovation indicators suggested for analysing different types of innovation, based on the primary focus and differences of each innovation type to avoid overlap. However, further investigation into the usefulness of various indicators and their capacity to reflect specific types of innovation would be very useful and relevant. Future research should focus on refining innovation measurement by investigating the relevance and precision of different indicators, developing standardised systems, and incorporating more detailed measurement methods. The lack of standardised systems for selecting and using innovation indicators underscores the need for an established framework to help researchers select more appropriate indicators and improve the precision of innovation evaluations.

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CRediT authorship contribution statement

Alina Stundziene: Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Vaida Pilinkiene:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Funding acquisition, Formal analysis. **Mantas Vilkas:** Writing – review & editing, Writing – original draft, Resources, Investigation, Formal analysis. **Andrius Grybauskas:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis. **Mantas Lukauskas:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Formal analysis.

Declaration of competing interest

The authors have no conflict of interest, financial or otherwise.

Supplementary materials

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