International Journal of Innovation Studies 9 (2025) 1–15

Contents lists available at ScienceDirect

International Journal of Innovation Studies

journal homepage: www.keaipublishing.com/en/journals/international-journal-of-innovation-studies

What typology of risks and methods for risk management in innovation projects?: A systematic literature review

Martha Orellano [a], Didier Gourc [b,*]

[a] Sustainability Department, Expleo Group, Toulouse, France
[b] IMT Mines Albi, Industrial Engineering Center, Toulouse University, Albi, France

ARTICLE INFO

Keywords:
Risk management
Innovation
R&D
Organisational innovation
Sustainable development

ABSTRACT

Performing an appropriate risk management methodology is essential to support early decision-making in innovation development projects. In parallel, research and practice in innovation have evolved over the last years, surpassing the sphere of new product development to address recent domains such as service development, business model innovation, and sustainability-oriented innovation. Henceforth, there is a need for comprehensive research to update the joint knowledge about innovation development and risk management. Through a systematic literature review, this research analyses and consolidates the knowledge of 98 articles published between 1998 and 2022. This analysis contributes to the literature by i) highlighting specific risks associated with the innovation development process; ii) classifying the methods and tools used to manage risks in innovation development projects; and iii) drawing out the future research directions crossing these two domains. The added value of our systematic review is based on an extended time frame and a broader definition of innovation, considering not only product or technology-oriented innovations but also service and business models ones. In practical terms, the study consolidates and presents the main risks project managers have to manage and the best methods to manage them, the importance of human-based approaches, especially in radical innovations.

1. Introduction

Innovation is essential for companies to remain competitive and to create high value compared to traditional product or service development (Freel et al., 2014; Chiambaretto et al., 2020). Therefore, exploring the factors that enable successful innovation development is crucial for companies' sustainability. Hence, there is a need to work on risk management approaches and tools applicable to innovation projects. According to the Frascati Manual (OECD, 2016), innovation can be defined as the transformation of an idea into a new or improved product or service, which can be commercialised.

Furthermore, several authors argue that risk and innovation are indissociable (Gurd and Helliar, 2017; Ali et al., 2017), because innovation development deals with a lot of uncertainty in both, the process and the outcome (Penide et al., 2013; Flemig et al., 2016; Ryman and Roach, 2022). Also, Gurd and Helliar (2017) highlight the direct relationship between risk and the level of value created through innovations. Indeed, the most the innovation is radical, the most it is riskier, the most value can be created, and the most competitive differentiation can be achieved by a company.

* Corresponding author.
E-mail addresses: martha.orellanoc@gmail.com (M. Orellano), didier.gourc@mines-albi.fr (D. Gourc).

https://doi.org/10.1016/j.ijis.2024.10.001
Received 11 March 2024; Received in revised form 3 August 2024; Accepted 28 August 2024
Available online 31 October 2024

Thus, as risk is an inherent characteristic of innovation, risk management methods should be involved in the innovation process from the early phases.

In the context of innovation, risk management is useful to identify the source and the type of risks, that can vary from slightly to very different from traditional product and service development, depending on the level of innovation disruption (Flemig et al., 2016). For instance, we can evoke classical risk factors, such as financial, technical, and market-oriented ones; but also, some risk factors more related to innovation, such as relational, societal, and hazardous ones. Identifying the risk factors and their level of criticality can elucidate early decisions about whether to launch or not an innovation (Flemig et al., 2016). Risk management methods might be also necessary to calculate the level of risk, to ensure as much as possible the achievement of the expected value to be created (Gurd and Helliar, 2017).

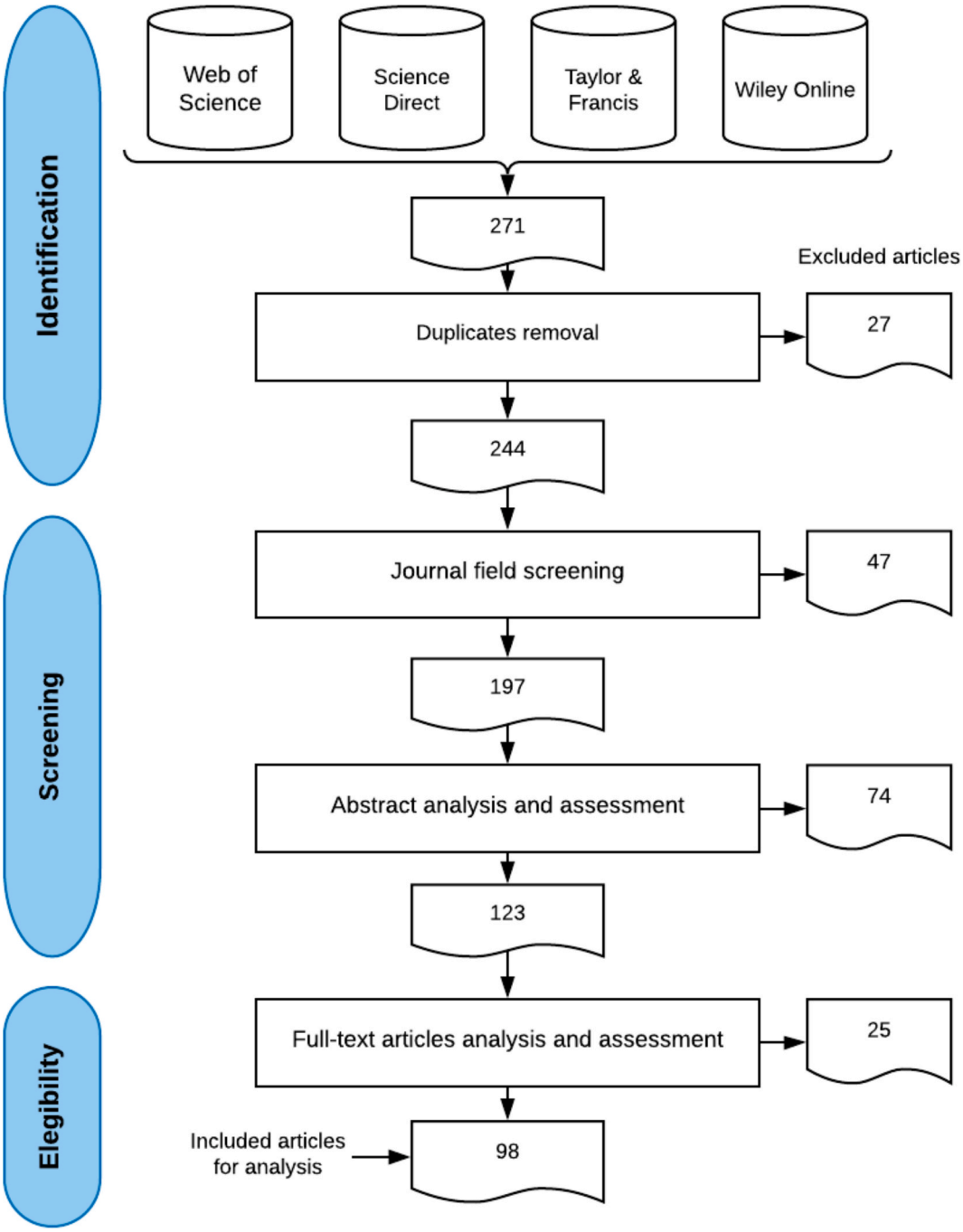

Fig. 1. Flow diagram of the systematic literature review based on the PRISMA framework.

According to the standard AFNOR (2003), the risk management of a project is defined as an iterative and structured process that allows a company to identify, evaluate, treat, control, and memorise the risks associated with a given project during its lifecycle. Besides, risk is defined as a probable event that can be manifested at a given phase of a project and interfere with the achievement of its goals (Nguyen et al., 2013). Existing literature and some international standards establish the risk management phases as: identification, estimation, evaluation, treatment, and control.

Although there are several risk management methods to deal with risks in traditional projects, they cannot always be adopted in the context of innovation (Deniaud et al., 2015). Innovation is differentiated from traditional products or services because it involves a higher level of uncertainty, because it might need interactions between several actors or stakeholders, directly or indirectly impacted by the innovation development. Furthermore, given the inexperience and the lack of historical data, innovation projects require more attention to the scope definition, which is also related to human interactions. Dealing with collaboration is not always integrated into classical risk management methods. Thus, there is a need for risk management methods to be adapted to the specificity of innovation.

To deal with the limits of the literature on innovation and risk management, this article performs a systematic literature review using the PRISMA methodology (Moher et al., 2015). 98 articles published between 1998 and 2022 are analysed to address three research objectives: i) identify specific risks associated with the innovation development process; ii) classify the methods and tools used to manage risks in innovation development projects; and iii) draw out the future research directions of risk management in innovation project development. A previous literature review studying the link between risk management and innovation has been carried out (da Silva Etges and Cortimiglia, 2019). This work presents an analysis of papers between 2003 and 2014, confirming the increasing interest in studying risk and innovation together. These authors focus on technological innovations related to products and processes at the enterprise level, providing a conceptual framework to analyse the risk events commonly present in technological-innovative companies. The added value of our systematic review is based on an extended time frame and a broader definition of innovation, considering not only product or technology-oriented innovations but also service and business models innovations.

The paper is structured as follows: in Section 2, we deploy the systematic literature review based on the PRISMA framework. Then, we perform a descriptive analysis of the literature in Section 3, detailing the temporal distribution of the reviewed articles, the main knowledge fields addressed, and the nature of the literature contributions. In Section 4, we present a thematic analysis, proposing a synthesised typology of risks for innovation projects, and an analysis of the methods implemented in each stage of risk management for innovation. In Section 5, the research perspectives are discussed, focusing on the necessity of implementing collaborative approaches to manage risks in innovation projects. Finally, the conclusions and limits of this work are drawn out in Section 6.

2. Research methodology

A systematic literature review is conducted to identify and analyse the relevant research investigating risk management in innovation development projects over the last years.

The main benefits of this methodology include the ability to identify relevant information from a growing volume of publications that may be similar or contradictory. The use of a compilation of articles provides an overall view of the literature, unlike the study of a limited body of literature. As a result, the findings and analyses that are produced are independent of the specificities of a single case study. Systematic reviews should be transparent and rigorous to ensure reliable findings and analysis. To conduct this review, the PRISMA protocol was implemented (Moher et al., 2015), particularly suited to our study's objective. This protocol comprehends four phases to conduct a systematic literature review: identification, screening, eligibility, and inclusion of a set of articles (Fig. 1). The research questions guiding the systematic literature review address the fields of engineering and management, and are defined as follows:

1. What are the specific risks associated with innovation development?
2. What are the methods and tools used to manage risk in innovation development projects?
3. What are the main research directions elucidated by the literature analysis of risk management in innovation development?

In the following, each step of the PRISMA methodology is described.

2.1. Identification

A set of keywords was defined based on the research questions and addressing two bodies of literature referring to risk management and innovation, mostly in the fields of engineering and management. The keywords included the combination of ("risk" or "risk management") AND ("innovation" OR "product innovation" OR "R&D" OR "service innovation" OR "business model innovation" OR "sustainable innovation"). The choice of these keywords aims to explore the relationship between risk management and the extended field of innovation. Innovation research has evolved in recent years, going beyond traditional product innovation and addressing current subjects such as service development, business model innovation, open innovation, and sustainability.

To conduct the literature review, four main databases were consulted: Science Direct, Web of Science, Taylor and Francis, and Wiley Online. The keywords were searched by "Title" and "Field" through the databases' research engines. Our systematic review covers a time frame between 1998 and 2022. Conference articles and book chapters were considered relevant given the emergency of some innovation-related topics, such as sustainable innovation and open innovation. Only English-written articles were considered. This step resulted in the identification of 271 articles. After omitting duplicates, 244 publications were gathered.

2.2. Screening

The screening consists of two stages, the journal fields filtering and then the abstract analysis. Firstly, the 244 articles identified from the previous step were filtered regarding the journal research field. 47 papers were excluded because they were published in journals outside the research fields of engineering, operations management, service development, risk management, innovation and technology management, and business management. For instance, the excluded papers belong to the fields of psychiatry, nursing, earth sciences, and finance. 197 papers were retained to proceed with the abstract analysis.

For the abstract analysis, two criteria were defined: i) application of risk management to at least one type of innovation (i.e., product, service, business model innovation, …); and ii) contribution to the research scope in engineering or management sciences. Two researchers performed a parallel and independent process of abstract reading and positioning concerning the two inclusion criteria. Only the papers matching the two criteria for the two researchers were included for further analysis. In case of divergence between the researchers' results, some discussions were carried out until reaching a consensus. Here, 74 papers were discarded. For instance, the excluded papers did not discuss the notion of risk management or address the concept of risk from a medical point of view. A portion of discarded articles did not address the convergence between risk management and innovation development processes. 123 articles were retained for full-text analysis.

2.3. Eligibility

The 123 selected articles were read entirely. An depth analysis was performed from both descriptive and thematic perspectives. The descriptive aspects guiding the reading process comprehend: time frame (1998–2022), research field (engineering and management sciences), research methodology (either theoretical or empirical), and type of contribution of the reviewed articles (e.g. mathematical model, theoretical framework, typology, etc.). Concerning the thematic aspects, two bodies of literature about innovation and risk management were considered: the risk management process frameworks proposed in AFNOR (2003), and an innovation process comprehending the stages of R&D, conceptualization, ramp-up, and commercialization (OECD, 2016). Only the articles demonstrating a contribution to the research questions were included for full descriptive and thematic analysis documented in the following sections.

98 articles were included in this literature review to consolidate the knowledge linking risk management and innovation development, identifying the main contributions and gaps in these joint research fields.

3. Descriptive analysis

3.1. Temporal distribution

Fig. 2 shows the article's distribution in the time frame, evidencing an increasing interest in the joint study of risk management and innovation development over time.

A seminal study performed by Bosworth and Jobome (1999) was identified, in which the risks of product and process innovation faced by a company are studied solely from the financial perspective. Then, although the literature about risk management and innovation emerged before the 2000s, a significant amount of studies can be observed only after 2012, totaling 75 articles in our database, 77% of our reviewed literature. The literature reveals that the notion of innovation is surpassing the traditional frontiers of new product development. For instance, the current transition from in-house to open innovation (Euchner, 2013; Brunswicker and Chesbrough, 2018), and the emergency of fields as business model innovation (Gao et al., 2012; Daosheng et al., 2015; Röth and Spieth, 2019; Hock-Doepgen et al., 2020), and sustainable innovation (Roper and Tapinos, 2016; Bi et al., 2014, 2015; Subramanian et al., 2016; Sun et al., 2020b, 2020a; Yan et al., 2021) drives the recent interest on risk management in the context of innovation.

3.2. Knowledge fields

Within the 98 consulted articles, there are 14 conferences and one book chapter. The journal articles are published in a total of 56 journals, the most relevant are listed in Table 1. For further analysis, the journals were classified by fields of knowledge.

Then, the journal articles were classified according to the Scopus categories. In the case of conference papers and book chapters, the

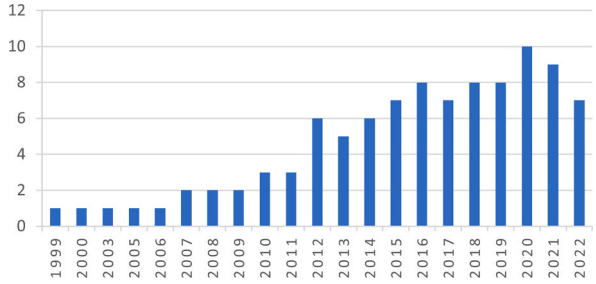

Fig. 2. Distribution of articles per year.

knowledge category was determined based on the main theme of the conferences and books, following, as for the journals, the Scopus categories. As shown in Fig. 3, 51% of the journals belongs to the field of business, management, and accounting; whereas 41% comes from the engineering field. In contrast, a minority of studies concerns the field of economics, econometrics, and finance (4%); social sciences (2%); and health sciences (2%).

It can be noticed that the number of publications belonging to the fields of business, management, and accounting, on the one hand, and engineering, on the other hand, is rather balanced, suggesting similar importance of the topic from these two perspectives. Some articles adopt a clear posture based on one of these perspectives, to the detriment of the other one. Articles concerning business, management and accounting field address the relationship between risk management and innovation from a behavioural perspective. For instance, Brown and Osborne (2013) argue that risk management in innovation is an organisational matter, affirming that a technocratic approach to risk management is not appropriate to deal with innovation. To these authors, innovation requires a governance approach to risk management, which implies a full discussion and negotiation of risks between all the concerned stakeholders.

Besides, the articles belonging to the engineering field focus on the techniques and tools for risk management. For instance, Chen (2018) argue that solutions for risk management in innovation should primarily contribute to the calculation of uncertainty in complex contexts and with a high level of accuracy. In this line, Keizer and Halman (2007) propose a novel method to diagnose and evaluate risks in radically innovative R&D projects, and Sovacool et al. (2014) use a statistical approach to analyse the risks of energy-related innovation projects from a cost-performance perspective.

In contrast to this siloed vision, many authors argue that both organisational and technocratic points of view are necessary to manage risks in any project (Hoecht and Trott, 2006; Ning and Ruoyu, 2007; Wang et al., 2010). For instance, for Hoecht and Trott (2006), innovation might be understood as a technological change impacting companies' operational processes, which also implies a profound organisational and behavioural transformation.

Table 2 presents the most relevant articles according to the number of citations, indicating their knowledge field.

3.3. *Literature's approaches and contributions*

The reviewed literature was analysed according to their research methodology, which has been classified into empirical and theoretical research. Also, an analysis was performed according to the type of contributions, classified into concept development and method proposal (Kothari, 2004).

Regarding the research methodology, some sub-categories were identified. The empirical research was classified into case study, survey research, and experimental research design. The theoretical research was subdivided into literature analysis, and mathematical theory building.

According to Fig. 4, most of the studies (71%) correspond to the empirical research category. This approach is useful for theory building and theory verification, and it is specially applied in emergent fields of study (Flynn et al., 1990). This strongly suggests that the joint study of risk management and innovation is still in an exploratory phase. The distribution among case study, survey, and experimental research design is rather equitable. The remaining 29% of the total analysed publications adopts theoretical research. In this category, mathematical theory formulation represents a minority, whereas literature analysis is predominant. Also, only one article corresponds to a systematic literature review studying the link between risk management and innovation (da Silva Etges and Cortimiglia, 2019). This work presents an analysis of papers between 2003 and 2014, confirming the increasing interest in studying risk and innovation together. These authors focus on technological innovation related to products and processes at the enterprise level, providing a conceptual framework to analyse the risk events commonly present in technological-innovative companies. The added value of our systematic review is based on an extended time frame (1998–2022) and a broader scope of innovation, considering not only product or technology-oriented innovation but also service and business model innovations.

Regarding the nature of the contributions of the reviewed literature, they mostly contribute to concept development in comparison

Table 1
Articles distribution among the most representative journals.

Journal	#	%
Technovation	7	7.29%
Journal of Business Research	4	4.17%
Sustainability	4	4.17%
Research-Technology Management	3	3.13%
Technological Forecasting and Social Change	3	3.13%
Technology Analysis and Strategic Management	3	3.13%
Innovation: The European Journal of Social Science Research	2	2.08%
Journal of Risk Research	2	2.08%
NanoImpact	2	2.08%
Public Management Review	2	2.08%
Public Money and Management	2	2.08%
Research Policy	2	2.08%
International Journal of Technology Management	2	2.08%
Other journals (only 1 article per journal)	43	44%
Conferences and book chapters	15	16%

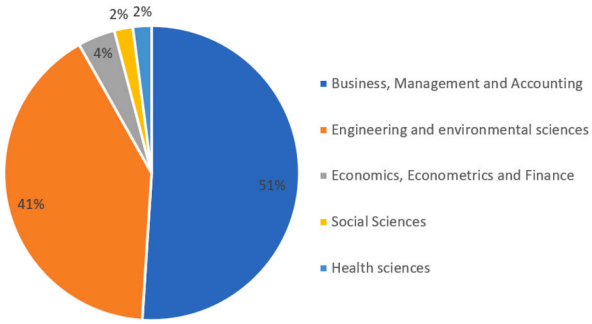

Fig. 3. Distribution of articles based on Scopus research field.

Table 2
List of the 10 most cited articles.

Article title	# citations	Authors	Knowledge field
Innovation risks of strategic outsourcing	361	Hoecht and Trott (2006)	Engineering
Risk and Innovation	337	Brown and Osborne (2013)	BMA[a]
A performance-oriented risk management framework for innovative R&D projects	274	Wang et al. (2010)	Engineering
Systemic innovation and risk: technology assessment and the challenge of responsible innovation	261	Hellström (2003)	BMA
Knowledge management capabilities and organizational risk-taking for business model innovation in SMEs	256	Hock-Doepgen et al. (2020)	BMA
Unraveling the link between managerial risk-taking and innovation: The mediating role of a risk-taking climate	213	García-Granero et al. (2015)	BMA
Does fiscal decentralization and eco-innovation promote renewable energy consumption? Analyzing the role of political risk	165	Su et al. (2021a)	Engineering
Managing functional diversity, risk taking and incentives for teams to achieve radical innovations	162	Cabrales et al. (2008)	BMA
Risk, innovation, electricity infrastructure and construction cost overruns: Testing six hypotheses	147	Sovacool et al. (2014)	Engineering
Taking risks in the face of uncertainty: An exploratory analysis of green innovation	138	Roper and Tapinos (2016)	BMA

[a] Business, Management and Accounting.

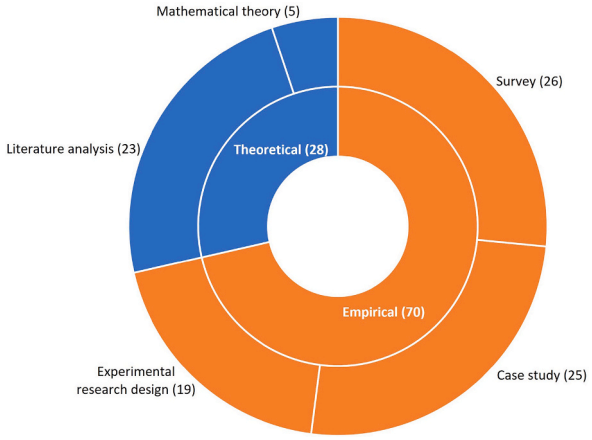

Fig. 4. Number of articles according to the methodological approach.

to the method-oriented proposals. Namely, 64% of the articles aims at establishing the main characteristics of risks in the context of innovation, as well as integrating emergent concepts such as open innovation, and analysing the opposite concepts of radical and incremental innovation. The other 36% of studies propose a method to evaluate risks in innovation projects. Among this percentage, some authors propose the implementation of existing risk management methods with some adaptations to the context of innovation, whereas most of the authors build novel *ad-hoc* methods. The above might reveal the limitations of existing risk management methods, applicable to traditional product or service development, and suggest that innovation projects might need specific methods, able to integrate a bigger complexity and uncertainty (Kalvet and Lember, 2010; Bertrand and St-Pierre, 2017; Hartwig and Mathews, 2020;

Ryman and Roach, 2022).

4. Thematic analysis

In the previous sections, we looked at the descriptive aspects of the reviewed literature; in this section, we analyse the content and contributions made in terms of risk typology, and the risk management methods used in the literature in the domain of innovation.

Defining a risk typology is an essential step in risk management, since there is not a unique risk classification that fits any type of project, inversely, each project involves specific risks according to its nature and context. Similarly, we have made the hypothesis that some methods are more suitable for managing risks in innovation projects than in traditional ones.

4.1. Typology of risks in innovation projects

Based on the analysis of the reviewed articles, we distinguished two classes of risks (Fig. 5): internal risks and external risks. Internal risks refer to the risks that exist within a company and that can be managed internally. Internal risks are risks that can be prevented or mitigated within the business. External risks are those that cannot be controlled by a company, they depend on the external environment. Several authors such as Azevedo-Sa et al. (2021); Mohammad et al. (2014) adopt this kind of risk classification.

4.1.1. Internal risks in innovation

For the internal risk class, this study reveals four sub-classes of risks: financial, organisational, operational, and relational risks.

Financial risks are the most cited in the reviewed literature, with around 30% of the articles treating this subject as one of the main risks to be considered in innovation projects. In innovation, these risks refer mainly to two factors: high investment levels, and the revenue diversification problem. For the former factor, Sun et al. (2020b) and Ali et al. (2017) highlight the return on investment (ROI) as a major preoccupation for innovative companies, which can be very long term considering the uncertainty of the innovation lifecycle driven by the market's acceptance. Innovative products and services involve high investments related to infrastructure, highly qualified human resources and knowledge, and marketing campaigns to accelerate customer acceptance. Also, according to Ali et al. (2017), the production process of innovation requires to access expensive technical material, to outsource some activities, and to adapt existing processes to new requirements, which could be very expensive. Concerning revenue diversification, Howell (2015) affirms that firms with a higher proportion of revenues coming from innovative products or services increase their financial risks because of the uncertainty about the level of revenues obtained from innovation. According to this author, the most a company diversifies their incomes between innovative and regular products and services, the least their financial risks will be.

Then, specific to innovation, the category of **relational risks** is addressed by around 20% of the analysed articles. This category concerns the risks related to the collaborative relationships taking place between the actors involved in an innovation project (Lowman et al., 2012; Subramanian et al., 2016; Crispeels et al., 2018; Osborne et al., 2020; Shandilya et al., 2020).

Firstly, Lowman et al. (2012) highlight the risk of dependency to external actors, such as suppliers, to access relevant knowledge and strategic resources in an innovation development process. In the specific case of outsourcing, the authors pointed out that it can interfere with a company's creativity improvement and reduce the percentage of value appropriation in a business transaction. Secondly, several authors point out the risk of opportunistic behaviour coming from partnerships, with the intention of one actor to appropriate resources and knowledge from its partner (Chou and Chou, 2011; Wu and Wu, 2014; Chiambaretto et al., 2020). Thirdly, Ali et al. (2017) discuss the risk of misalignment regarding partners' production processes as well as conflicting decision governance approaches, which can lead to long and inefficient innovation processes or innovation failure. Finally, some authors evoke the notion of data security as a new risk regarding innovation involving data-sharing (Ali et al., 2017; Paluch and Wünderlich, 2016). For instance, in cloud-based service innovations, customers might not have control over their own data privacy, provoking a fear of misuse or appropriation and incorrect exploitation of their data, leading to resistance to such type of data-driven innovations (Paluch and Wünderlich, 2016).

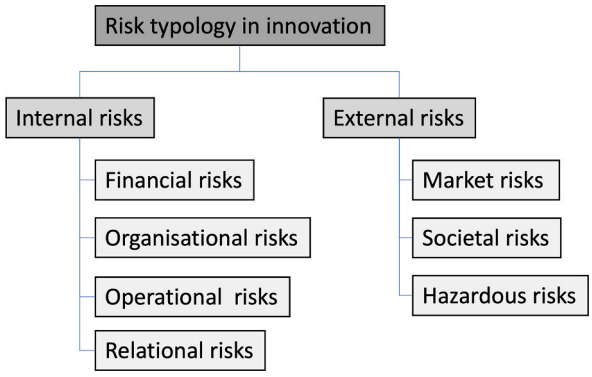

Fig. 5. Typology of risk in innovation based on our systematic literature review.

Organisational risks are evoked in 10% of the reviewed works, nevertheless, it appears to be a critical aspect for innovations to be successful (Osborne et al., 2020). According to the reviewed articles, it depends on two risk factors, one concerning the risk profile of decision-makers and the other concerning the organisational culture of the company. Related to the former, some authors (Keizer and Halman, 2007; Murro, 2013; Meroño-Cerdán et al., 2018; Drakeman and Oraiopoulos, 2020; Giaccone and Magnusson, 2022) argue that an excessive level of control exercised by the decision-makers can sabotage the innovation process and its eventual outcomes, it can provoke the precipitated abandon of highly potential innovation projects. Concerning the organisational culture, Hock-Doepgen et al. (2020) postulate that companies with high-risk tolerance are more alike to identify and exploit innovative business opportunities, while risk-averse companies do not. Moreover, risk-taking companies develop their abilities to acquire and exploit new knowledge from the external environment. In the same line, Osborne et al. (2020) present risks as a necessary component of innovation, that should be managed instead of avoided. They suggest that innovative companies might adopt a risk governance approach based on risk negotiation and supported by the ability to learn from risky situations, in contrast to technocratic approaches that are suitable for regular products and services development.

Finally, concerning the **operational risks**, 10% of the articles in this review evokes them, mostly oriented towards the management of knowledge. Hock-Doepgen et al. (2020) highlight the risks related to the company's knowledge management maturity. These authors emphasize the ability of a company to acquire, convert and apply knowledge coming from the outside, which is essential to build the know-how and the innovation advantage of a company (Yang, 2008; Banerjee and Sharma, 2015). Innovative companies are not only those capable of developing innovations by themselves but also those able to acquire and integrate external knowledge quickly and to co-create value with strategic partners (Banerjee and Sharma, 2015). This can be the case for a company that decides to outsource a part of its activity (Yang, 2008).

Indeed, in innovative business models, companies should master and update their internal knowledge and be able to constantly integrate new knowledge from their partners and the external environment (Ali et al., 2017; Hock-Doepgen et al., 2020). Also, companies should be aware of technological advancements and the evolution of customers needs to innovate in a viable way and be capable of conducting internal processes evolution accordingly. Nevertheless, internal knowledge should also be maintained, for instance, Ali et al. (2017) point out the need for training on a regular basis the internal human resources, to be aligned with the new requirements of the market and avoid the risk of depending too much on external partners.

Another risk factor related to the operational risk class concerns the maturity of the innovative product or service. According to Keizer and Halman (2007), mainly in radical innovations, which have longer lifecycles than incremental innovations, there is high uncertainty about the ability of the new product or service to fulfil the specifications it was designed for. The above, induce a high risk for the company to predict their market success accurately. Roper and Tapinos (2016) argue that radical innovations can face some time constraints, and fast decision-making can be required, which may reduce the innovation quality and thus the market success of the innovative product or service. Furthermore, Keizer and Halman (2007) cite the risk of not having the right suppliers to provide in a sustainable way the required resources to produce the innovative product or service (i.e. resource availability).

4.1.2. External risks in innovation

This class is made up of three sub-classes: market, societal, and hazardous risks.

Market risks are treated by about 15% of the reviewed works and concern the risks linked to the customer's acceptance of innovations. In innovation contexts, market risks can be higher than in traditional products or services, due to the uncertainty of the use phase which can provoke a high fluctuation in the demand (Howell, 2015). For instance, Paluch and Wünderlich (2016) highlight the financial risk perception of customers. Indeed, when buying innovative products or services, customers can face non-transparent pricing or unexpected needs for buying after-sales services. Moreover, in B2B contexts, Nahar et al. (2012) and Ali et al. (2017) highlight the risk of non-compatibility between the customer and provider, for example, a cloud-based service can not be adapted to certain security requirements of a specific customer needing to stock their data. Those factors can provoke some customers' aversion to buying innovations.

In addition, 12% of the articles discuss the **societal risks** implied in innovation development. These risks are those injected by the existence of governmental policies and the influence of the media on public opinion, which can generate societal aversion and block the development of certain innovations. Concerning governmental policy, Mastroeni et al. (2021) conduct exploratory work in the field of agricultural biotechnology innovation, pointing out the political and societal dimensions of innovation development, especially in staple industries such as agriculture. This work highlights the lack of objectivity that can exist in some policies, based on the "precautionary principle", which is adopted mostly when a product or service may have dangerous effects on human health. This principle can be based on decision-makers' judgement, according to their values or their political interests, rather than on scientific evidence. Thus, the politicisation and the lack of scientific rigour and transparency in certain policies might be a critical barrier to innovation development (Torugsa and Arundel, 2017; Osborne et al., 2020). Moreover, the literature suggests that there are some risks induced by media scrutiny. According to Boyd et al. (2013), the risk perception of emerging technologies plays an influential role in innovation processes, and media plays an important role in building the public's risk perception about technology and ongoing innovations. Often, the media used intuitive reasoning to explain risks, instead of being based on scientific evidence, and those biases are transmitted to their audience, constituting a barrier to societal acceptance of radical innovations.

Finally, the **hazardous risks** are evoked by 11% of the analysed articles and constitute a particular risk category (Köhler and Som, 2014; Subramanian et al., 2016; Franken et al., 2020). It can be classified into internal risks as well as external ones, depending on the capacity of a company to anticipate them. Hazardous risks refer to the side effects of some innovations, mainly product and technological-oriented ones, which may impact the environment and the safety and human health. Given the lack of knowledge involved in innovation development, for instance, the unknown long-term effects of some technologies, hazardous risks can be very

hard to determine and very difficult to be accepted by society. Moreover, hazardous risks of innovative products can be identified by some users in the latter phases, as the use or disposal ones, and can generate a negative reaction in society to current and future innovations.

Table 3 synthesizes the risk classes (2), risk categories (7), and risk factors (16) identified from the analysed literature, which are proper to the context of innovation. Furthermore, we have crossed the identified risk elements with the phases of the innovation process. According to OECD (2016), the innovation phases can be classified as the R&D phase (corresponding to the idea generation and concept development), the Ramp-up phase (concerning the production stabilisation), and the Market phase (regarding the commercialization of the innovation). In addition, considering the literature findings, we have identified two important innovation phases in matters of risk management, corresponding to the Use and Disposal phases. Although these two phases come after the innovation development itself, probable side effects can occur at that moment of the innovation lifecycle and should be anticipated during the early development phases (Köhler and Som, 2014; Dillerup et al., 2018; Nechaev et al., 2017). In Table 3, we represent by an "x" the occurrence of one risk at a given stage of the innovation lifecycle. Nevertheless, all the risks should be anticipated as much as possible from the early stages of the innovation process. As main insights, we observe that the risk factors "partner dependency" and "governmental policies" can be materialised at any stage of the innovation process, this might indicate their importance in innovation risk management. For instance, some governmental policies can sabot the development of radical innovations at any moment and it might be definitive or hard to overcome. Furthermore, we can notice that most of the risks can be manifested in the market or commercialization stage of innovation, which is partially explained by the uncertainty about the market acceptance, which can trigger the materialisation of other types of risks such as financial, operational, and or societal. Finally, the hazardous risks are in general materialised during the use and disposal stages of the innovation process, and their impact can be enormous since it implies the health and security of human beings and their living environment.

Table 3
Risks factors in innovation projects.

Risk			Innovation process					References
Class	Category	Factor	R&D	Ramp-up	Market	Use	Disposal	
Internal	Financial	Investment level	x	x	x			Lebedev et al. (2022); Zhou et al. (2021); Ali et al. (2017); Xu and Tang (2017); Gurd and Helliar (2017); Flemig et al. (2016); Ai-li and Xiao-yi (2013)
		Revenue diversification			x			Howell (2015)
	Relational	Opportunistic behaviour	x	x	x			Sun et al. (2020b,a); Ali et al. (2017); Torugsa and Arundel (2017); Roper and Tapinos (2016); Wu and Wu (2014)
		Process alignment	x	x		x		Whyles et al. (2015); Chou and Chou (2011)
		Data security			x	x		Ali et al. (2017); Roper and Tapinos (2016); Nahar et al. (2012)
		Partner dependency	x	x	x	x	x	Chiambaretto et al. (2020); Sun et al. (2020b,a); Howell (2015); Wu and Wu (2014); Lowman et al. (2012); Chou and Chou (2011)
	Organisational	Manager risk profile	x					Lendowski et al. (2022); Khachaturyan et al. (2019); Usai et al. (2018); Ali et al. (2017)
		Organisational culture	x					Lima Rua et al. (2022); Zhao et al. (2021); Hock-Doepgen et al. (2020); Sun et al. (2020b,a); Röth and Spieth (2019); Khachaturyan et al. (2019); Usai et al. (2018)
	Operational	Knowledge maturity	x	x	x			Zhao et al. (2021); Zhou et al. (2021); Yan et al. (2021); Hock-Doepgen et al. (2020)
		Product/service maturity		x	x	x		Sun et al. (2020b,a)
		Resources availability		x	x			Ambulkar et al. (2022); Hrytsenko (2021); Roper and Tapinos (2016)
External	Market	Customer acceptance			x	x		Chiambaretto et al. (2020); Hock-Doepgen et al. (2020); Torugsa and Arundel (2017); Flemig et al. (2016); Howell (2015)
	Societal	Governmental policies	x	x	x	x	x	Hrytsenko (2021); Su et al. (2021a,b); Qin et al. (2021); Torugsa and Arundel (2017); Roper and Tapinos (2016); Wu and Wu (2014)
		Media scrutiny			x	x	x	Torugsa and Arundel (2017); Boyd et al. (2013)
	Hazardous	Environmental impact				x	x	Yan et al. (2021); Franken et al. (2020); Shandilya et al. (2020); Schulte and Hallstedt (2018b,a); Subramanian et al. (2016); Köhler and Som (2014)
		Human safety				x	x	Franken et al. (2020); Shandilya et al. (2020); Schulte and Hallstedt (2018b,a); Rodríguez (2018); Subramanian et al. (2016); Köhler and Som (2014); Boyd et al. (2013)

In conclusion, concerning the first research question, we have identified internal and external risks related to innovation, which are constituted by several risk categories and factors. Specific to innovation, we have identified two new categories of risk: relational risks, derived from the interactions between two or more partners involved in innovation development (Chou and Chou, 2011); and hazardous risks, which correspond to the side effects that product or service innovations can generate during their lifecycle, mostly manifested in the use and disposal phases, regarding the environment and human health (Köhler and Som, 2014). Besides, although we have identified different categories and levels of risks, there is interdependence among most risk elements. For instance, operational risks can provoke or reinforce market risks; hazardous risks can aggravate societal or governmental-related risks, and it can be the case for other risk categories. Thus, it is necessary to seek methods able to analyse the risks' interdependence in innovation projects.

4.2. Risk management methods in innovation

According to the analysed literature, 23 risk management methods with applications in the context of innovation have been identified in 63 articles (Table 4). Most of them are implemented in the phases of identification and evaluation (25 and 24 articles respectively); then, the treatment phase counts 8 works; and, the least addressed phases are context setting and capitalisation (4 and 2 papers respectively).

The **context setting** phase is considered non-mandatory in classical projects, but is strongly recommended in innovation-oriented ones. However, it is still a weakly addressed phase in risk management and the methods are rather based on informal stakeholders' participation to determine the scope of the project and the risks spectrum to be considered (Subramanian et al., 2016; Ali et al., 2017; Osborne et al., 2020; Shandilya et al., 2020). Particularly in radical innovation projects, the involvement of stakeholders is almost mandatory to avoid premature innovation failure, considering that the most the innovation is radical, the most the collaboration with multi-disciplinary partners is required (Juraj and Mária; Shandilya et al., 2020; Li et al., 2022). This is particularly true if the innovation implies the potential side effect impacting human health or the environment.

The **identification** phase is characterised by the use of several and diverse methods, which are mainly based on expert or stakeholder consulting and literature review, aiming at establishing a list of risks appropriate to the nature of the specific project (Keizer and Halman, 2007; Wang et al., 2010; Grubisic et al., 2011; Sun et al., 2020b; Osborne et al., 2020). In the case of some high-technology innovations involving human well-being, for example on nano-materials (Franken et al., 2020; Shandilya et al., 2020)

Table 4
Risks management (RM) methods in innovation projects.

RM stage[a]	Method	# cited	References
Context (1)	Participatory methods	5	Li et al. (2022); Shandilya et al. (2020); Osborne et al. (2020); Ali et al. (2017); Subramanian et al. (2016)
	Expert consulting	10	Sun et al. (2020b,a); Osborne et al. (2020); Puente et al. (2019); Suprin et al. (2019); Zhang et al. (2019); Deptuła (2017); Neumann et al. (2016); Wang et al. (2010); Keizer and Halman (2009, 2007)
	Literature review	6	Bi et al. (2015); Dockner and Siyahhan (2015); Bi et al. (2014); Miorando et al. (2014); Ai-li and Xiao-yi (2013); Ghadim et al. (2005); Bosworth and Jobome (1999)
Identification (9)	Brainstorming	2	Shandilya et al. (2020); Jen and Liu (2012)
	Risk listing	2	Ali et al. (2017); Subramanian et al. (2016)
	Failure mode and effects analysis	2	Köhler and Som (2014); Jen and Liu (2012)
	Risk breakdown structure	2	Schuhmacher et al. (2021); Stosic et al. (2017)
	Stakeholders consulting	2	Gurd and Helliar (2017); Keizer and Halman (2007)
	Survey	1	Luo and Hu (2015)
	Sytem dynamic modelling	1	Wu et al. (2010)
	Expert consulting	6	Dahmani et al. (2020); Suprin et al. (2019); Deptuła (2017); Gurd and Helliar (2017); Neumann et al. (2016); Wu et al. (2010)
	Likert-alike scale	5	Dahmani et al. (2020); Suprin et al. (2019); Ali et al. (2017); Keizer and Halman (2009)
	Fuzzy evaluation	4	Puente et al. (2019); Chen (2018); Luo and Hu (2015); Ai-li and Xiao-yi (2013)
	Analytical hierarchical process	3	Sun et al. (2020b,a); Zhang et al. (2019); Bi et al. (2015)
Evaluation (10)	Lifecycle assessment	3	Shandilya et al. (2020); Subramanian et al. (2016); Köhler and Som (2014)
	Statistics modeling	3	Wang and Bi (2021); Chursin et al. (2019); Miorando et al. (2014); Wang et al. (2010)
	Econometric modeling	2	Ghadim et al. (2005); Bosworth and Jobome (1999)
	Risk matrix	2	Dahmani et al. (2020); Stosic et al. (2017)
	Failure mode and effects analysis	1	Jen and Liu (2012)
	Investment mathematics model	1	Dockner and Siyahhan (2015)
Treatment (2)	Risk matrix	5	Sun et al. (2020b,a); Shandilya et al. (2020); Ali et al. (2017); Bi et al. (2015); Köhler and Som (2014)
	Expert consulting	4	Suprin et al. (2019); Gurd and Helliar (2017); Neumann et al. (2016); Wang et al. (2010)
Capitalisation (1)	Reporting	3	Shandilya et al. (2020); Suprin et al. (2019); Köhler and Som (2014)

[a] Number of methods identified in this phase.

or in pharmaceutics (Jen and Liu, 2012; Puente et al., 2019), the risk identification stage might follow strict protocols, which consider a fine typology of risks and should be validated by an expert team and communicated to the relevant stakeholders, who might be impacted by the innovation (Gurd and Helliar, 2017).

Concerning the **evaluation** phase, most of the implemented methods are rather numerical (e.g., Fuzzy Evaluation, Analytical Hierarchical Process, Lifecycle Assessment) than human-based (e.g., expert consulting). For example, the Lifecycle Assessment is a numerical approach that aims at calculating the details of environmental impacts associated with the use of a given product from the beginning to the end of its life. In the analysed literature, this method is mostly implemented in product and technological-oriented innovations as is the case of nanotechnology (Köhler and Som, 2014; Shandilya et al., 2020). Nevertheless, we can observe the use of some quasi-mathematical or probabilistic methods, integrating the uncertainty proper to innovation. For instance, the fuzzy evaluation, in which some judgment parameters are answered by subjective opinions and then calculated throughout fuzzy numbers (Puente et al., 2019); the implementation of Analytical Hierarchical Process (Bi et al., 2015; Chen, 2018), which is a numerical approach supported by the opinion of experts; or the use of Likert scales, which are also supported by subjective decisions of a group of experts and/or non-experts (Keizer and Halman, 2007; Ali et al., 2017).

Then, the **treatment** phase reveals the use of traditional methods such as the risk matrix, involving the classical strategies of risk management such as avoiding, mitigation, or acceptance (Köhler and Som, 2014; Ali et al., 2017; Shandilya et al., 2020). Nevertheless, the authors emphasise the need for accepting risks as part of innovation, opting by managing risks instead of avoiding them.

Finally, the **capitalisation** phase is performed throughout internal and external reporting (Shandilya et al., 2020; Köhler and Som, 2014). Here, most authors evoke the need to document failed innovations, instead of abandoning them (Shandilya et al., 2020).

In general, around 50% of the implemented methods in the context of innovation involve a lot of human interactions, for instance, experts and stakeholders consulting, and brainstorming workshops.

5. Research perspectives

First, concerning the typology of risks, we summarised and categorised a list of risk factors that can influence the development of innovations, whether technological or non-technological. Here, we performed an analysis of the appearance of the different risks during the innovation process, regardless of the type of innovation. Nevertheless, we noticed that the level of criticality of each type of risk can vary depending on the type of innovation, whether radical or incremental, or technological or non-technological. For instance, innovations such as nanotechnology, which are technological and rather radical, can carry more critical societal risks than other types of innovation, as they can impact human health and safety (Shandilya et al., 2020; Franken et al., 2020). For future research, it might be interesting to explore the link between each type of innovation and the criticality of the different risk factors that have been identified throughout this research. This research track can be useful for project or innovation managers, risk analysts, and decision-makers to perform more appropriate risk management approaches in their innovation projects.

Second, we synthesised and classified the risk management methods used in innovation, according to the phases of risk management proposed by AFNOR (2003). We highlighted the most and the least used methods for innovation projects in general. For future research, we note from the literature analysis that innovation projects require to adopt collaborative methods to manage the risks (Gurd and Helliar, 2017; Crispeels et al., 2018; Osborne et al., 2020; Shandilya et al., 2020; Giaccone and Magnusson, 2022). In this line, innovation might need *ad-hoc* approaches, based on human interactions and are able to support consensus and harmonisation between the different stakeholders' perceptions of risks (Hall et al., 2014). Furthermore, innovative risk management approaches should be evolutionary, and able to integrate new information during the innovation process (Subramanian et al., 2016). These

Fig. 6. Representation of a Materiality Matrix. Each point (R_i) represents a risk factor.

insights are particularly applicable to the evaluation phase.

Concerning the stakeholders' perceptions of risks, we highlight the need for establishing a balance between the perceived risks and benefits, at the individual and project levels. Understanding the above might help establish an appropriate acceptance level of risks, and reduce the premature abandonment of innovations with a high potential of value creation (Hall et al., 2014). To address this challenge, we consider that it might be helpful to define the level of importance of each stakeholder's opinion, according to their legitimacy regarding the nature of the innovation and its potential effects. Addressing this research question can allow a more accurate risk evaluation and a better decision-making process.

Some clues to address this challenge can be explored through radical innovations involving health and safety risks. Nanotechnology-related innovations might be an example since the participation of several stakeholders is mandatory in this kind of innovation (Köhler and Som, 2014; Subramanian et al., 2016; Franken et al., 2020; Shandilya et al., 2020). Moreover, a suitable approach concerning the stakeholder engagement in innovation should enable the evaluation of risk from the company's point of view versus the key stakeholders' perceptions. An existing tool that can respond to this need is called the Materiality Matrix (MM) (Fig. 6), issued from the field of Corporate Social Responsibility (CSR) (Calabrese et al., 2015; Torelli et al., 2019). The materiality notion emerged as the most important element in the Global Reporting Initiative (GRI) concerning Sustainability impacts guidelines (Calabrese et al., 2015). From the practical point of view, the MM intervenes in the evaluation phase of risk management. It consists of a matrix crossing the level of importance of given factors for the stakeholders and the level of importance of the same factors for a single company, which could be the leader of an innovation project. This approach aims to assess and select the most relevant factors for all the stakeholders involved in the project, which are visualized in the upper right quadrant of the graph (Fig. 6). Previous to building the matrix, it is necessary to identify the key stakeholders involved in the project, then to identify the risk factors collectively. After that, the construction of the MM can start. First, each stakeholder should estimate the importance of a risk factor from its point of view, then the project leader company should do it as well, using for instance, a Likert scale. Each point in Fig. 6 represents the estimation of a risk factor, resulting from the intersection between the average of the stakeholders' estimation (in the ordinates) and the estimation of the leading company (in the abscissas).

Furthermore, the Materiality Matrix approach could be coupled with other evaluation methods such as the risk matrix to determine the risk criticality or even quantitative methods such as the Lifecycle Assessment (LCA) (Subramanian et al., 2016), or investment mathematics models to evaluate the risks on an objective base (Dockner and Siyahhan, 2015).

6. Conclusion

Given the uncertainty involved in innovation projects and their strategic nature for the sustainability of companies, risk management approaches are considered to be crucial for these projects' success. The involvement of risk management in innovation projects has received increasing attention from innovation researchers and practitioners over the last two decades. There is a need to conduct a comprehensive state-of-the-art study to identify the features and challenges of risk management in innovation and set grounds for future research. This study follows a systematic review approach, based on the PRISMA methodology. 98 papers published from 1998 to 2022 have been investigated. The papers have been analysed according to the source, domain, timeline, and contributions to the subject. Descriptive and thematic analyses were conducted to answer the research questions argued in the beginning.

The evaluation of the selected papers allowed us to provide a comprehensive description of the risk typology and dedicated tools for risk management in innovation projects. The analysis carried out in this paper may help researchers understand the concepts and risk classification specific to innovation projects.

Two main classes of risk were identified: internal risks and external risks. For the internal risks class, the study reveals four sub-classes: financial, organisational, operational, and relational risks. The external risks class is made up of three sub-classes: market, societal, and hazardous risks. Relational, societal, and hazardous risks were identified as particularly important risk factors in the context of innovation.

6.1. Implications

Innovation projects involve more uncertainty than traditional projects, therefore a higher level of risk for companies that would like to improve their competitive advantage through innovation. Our study has implications for practitioners, as the classes of risk and the main tools and techniques used for each stage of the risk management process are clearly defined. The thematic analysis describes the phase of occurrence of each identified risk factor, enabling practitioners to anticipate risks during the innovation process. To help decision-makers of innovative companies, this study procures a structured typology of risks that allows them to anticipate risks in the early phases of an innovation project. A good anticipation of risks helps companies to manage them better. Still, it can help companies decide if they should continue or stop an innovative project, depending on their capacity to manage the identified risks and their effects on their business. This study provides a summary of methods for each phase of a risk management approach and adapted to innovation projects, based on scientific literature. This summary helps decision-makers choose appropriate methods to identify, evaluate, and treat the risks they might deal with, taking into consideration their innovation context. Furthermore, concerning the methods to manage risks in innovation projects, the reviewed literature reveals the need for considering human interactions as a major feature of innovation projects. Thus, collaborative and human-based methods should be implemented in most cases, especially in radical innovations. Therefore, this study encourages decision-makers and project managers to structure risk management approaches and tools, paying particular attention to the benefits of human expertise in such an approach. Also, the phases of context definition and capitalisation involved in risk management acquire higher importance in innovation projects in comparison to traditional product or

service development projects.

Lastly, the article contributes to a better understanding of the period of occurrence of the main risks enabling project managers to anticipate and mitigate them.

6.2. Limitations

It is important to acknowledge certain limitations of this study. Firstly, as the study is based on existing literature, it may not fully capture some of the complexities and valuable insights present in real start-up environments. In addition, the study's findings are dependent on the quality and relevance of the selected publications. Despite a comprehensive search, some relevant papers may have been missed. Finally, the study does not include primary data collection methods, such as interviews and surveys, which could provide a more in-depth understanding of the actual experiences and outcomes of entrepreneurs using these strategies.

Secondly, regarding the risk typology, our contribution consists of the categorisation of risk factors, however, we did not consider the differences that might exist according to the type of innovation.

6.3. Future research

Future research can further analyse the link between the types of risk factors and their criticality and the type of innovation being addressed. Finally, some weaknesses concerning the risk management methods for innovation projects were identified and discussed. For instance, innovation might need *ad-hoc* approaches, which are based on human interactions and are able to support consensus and harmonisation between the different stakeholders' perceptions. To address this limit, we outlined a research track concerning the Materiality Matrix (MM) approach, issued from the Corporate Social Responsibility domain. This method can help academics and practitioners balance multiple stakeholders' points of view in matters of risk estimation in the context of innovation.

Ethics statement

Not applicable because this work does not involve the use of animal or human subjects.

Declaration of competing interest

The authors declare no conflict of interest.

References

AFNOR, 2003. Norme AFNOR FD X50-117, Management de projet - Gestion du risque - Management des risques d'un projet.

Ai-li, L., Xiao-yi, S., 2013. Research on the financial risk evaluation of the innovative enterprise. In: 2012 First National Conference for Engineering Sciences (FNCES 2012).

Ali, A., Warren, D., Mathiassen, L., 2017. Cloud-based business services innovation: a risk management model. Int. J. Inf. Manag. 37, 639–649. https://doi.org/10.1016/j.ijinfomgt.2017.05.008.

Ambulkar, S., Ramaswami, S., Blackhurst, J., Johnny Rungtusanatham, M., 2022. Supply chain disruption risk: an unintended consequence of product innovation. Int. J. Prod. Res. 60, 7194–7213.

Azevedo-Sa, H., Zhao, H., Esterwood, C., Yang, X.J., Tilbury, D.M., Robert, L.P., 2021. How internal and external risks affect the relationships between trust and driver behavior in automated driving systems. Transport. Res. C Emerg. Technol. 123.

Banerjee, S., Sharma, A.K., 2015. Co-creation as a risk-sharing strategy for the development of innovative EUR lithography technology in the semiconductor industry. Technol. Anal. Strat. Manag. 27, 1097–1113.

Bertrand, J., St-Pierre, J., 2017. Product Innovation in SMEs: Risk Identification Capacities. Risk Management: Lever for SME Development and Stakeholder Value Creation, pp. 127–147.

Bi, K., Huang, P., Ye, H., 2015. Risk identification, evaluation and response of low-carbon technological innovation under the global value chain: a case of the Chinese manufacturing industry. Technol. Forecast. Soc. Change 100, 238–248.

Bi, K.x., Ye, H., Ma, H.z., 2014. Research on risk evaluation of low-carbon technology innovation in Chinese manufacturing under the conditions of globalization. In: 2014 International Conference on Management Science & Engineering 21th Annual Conference Proceedings. IEEE, pp. 1651–1657.

Bosworth, D., Jobome, G., 1999. The measurement and management of risk in r&d and innovation. Int. J. Technol. Manag. 18, 476–499.

Boyd, A.D., Liu, Y., Stephens, J.C., Wilson, E.J., Pollak, M., Peterson, T.R., Einsiedel, E., Meadowcroft, J., 2013. Controversy in technology innovation: contrasting media and expert risk perceptions of the alleged leakage at the Weyburn carbon dioxide storage demonstration project. Int. J. Greenh. Gas Control 14, 259–269. https://doi.org/10.1016/j.ijggc.2013.01.011.

Brown, L., Osborne, S.P., 2013. Risk and innovation: towards a framework for risk governance in public services. Publ. Manag. Rev. 15, 186–208.

Brunswicker, S., Chesbrough, H., 2018. The adoption of open innovation in large firms: practices, measures, and risks a survey of large firms examines how firms approach open innovation strategically and manage knowledge flows at the project level. Res. Technol. Manag. 61, 35–45.

Cabrales, Á.L., Medina, C.C., Lavado, A.C., Cabrera, R.V., 2008. Managing functional diversity, risk taking and incentives for teams to achieve radical innovations. R&d Management 38, 35–50.

Calabrese, A., Costa, R., Rosati, F., 2015. A feedback-based model for CSR assessment and materiality analysis. Account. Forum 39, 312–327. https://doi.org/10.1016/j.accfor.2015.06.002.

Chen, T.Y., 2018. A novel risk evaluation method of technological innovation using an inferior ratio-based assignment model in the face of complex uncertainty. Expert Syst. Appl. 95, 333–350. https://doi.org/10.1016/j.eswa.2017.11.038.

Chiambaretto, P., Bengtsson, M., Fernandez, A.S., Näsholm, M.H., 2020. Small and large firms' trade-off between benefits and risks when choosing a coopetitor for innovation. Long. Range Plan. 53, 101876. https://doi.org/10.1016/j.lrp.2019.03.002.

Chou, D.C., Chou, A.Y., 2011. Innovation outsourcing: risks and quality issues. Comput. Stand. Interfac. 33, 350–356. https://doi.org/10.1016/j.csi.2010.10.001.

Chursin, R., Yudin, A., Grosheva, P.Y., Filippov, P., Butrova, E., 2019. Tool for assessing the risks of r&d projects implementation in high-tech enterprises. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, 012005.

Crispeels, T., Willems, J., Scheerlinck, I., 2018. Public–private collaborations in drug development: boosting innovation or alleviating risk? Publ. Manag. Rev. 20, 273–292.
Dahmani, S., Boucher, X., Gourc, D., Peillon, S., Marmier, F., 2020. Integrated approach for risk management in servitization decision-making process. Bus. Process Manag. J. 26, 1949–1977.
Daosheng, L., Xiaona, Z., Pan, G., Xiaoyan, M., 2015. Research of commercial cluster development risk estimate based on business model innovation. In: 2015 AASRI International Conference on Circuits and Systems (CAS 2015). Atlantis Press.
Deniaud, I.F., Marmier, F., Gourc, D., 2015. Alliances decision-making in NPD: a risk point of view. IFAC-PapersOnLine 48, 942–947.
Deptuła, A.M., 2017. Analysis of criteria used in the risk assessment of technical innovations. Procedia Eng. 182, 135–142.
Dillerup, R., Kappler, D., Oster, F., et al., 2018. Improving the management of innovation risks-r&d risk assessment for large technology projects. J. Manag. Strat. 9, 31–52.
Dockner, E.J., Siyahhan, B., 2015. Value and risk dynamics over the innovation cycle. J. Econ. Dynam. Control 61, 1–16. https://doi.org/10.1016/j.jedc.2015.07.005.
Drakeman, D., Oraiopoulos, N., 2020. The risk of de-risking innovation: optimal r&d strategies in ambiguous environments. Calif. Manag. Rev. 62, 42–63.
Euchner, J., 2013. The uses and risks of open innovation. Res. Technol. Manag. 56, 49–54.
Flemig, S., Osborne, S., Kinder, T., 2016. Risky business—reconceptualizing risk and innovation in public services. Publ. Money Manag. 36, 425–432. https://doi.org/10.1080/09540962.2016.1206751.
Flynn, B.B., Sakakibara, S., Schroeder, R.G., Bates, K.A., Flynn, E.J., 1990. Empirical research methods in operations management. J. Oper. Manag. 9, 250–284.
Franken, R., Heringa, M.B., Oosterwijk, T., Dal Maso, M., Fransman, W., Kanerva, T., Liguori, B., Poikkimäki, M., Rodriguez-Llopis, I., Säämänen, A., Stockmann-Juvala, H., Suarez-Merino, B., Alstrup Jensen, K., Stierum, R., 2020. Ranking of human risk assessment models for manufactured nanomaterials along the Cooper stage-gate innovation funnel using stakeholder criteria. NanoImpact 17, 100191. https://doi.org/10.1016/j.impact.2019.100191.
Freel, M., Robson, P.J., Jack, S., 2014. Risk capital constraints to innovation in services. J. Bus. Ind. Market. 29, 476–486.
Gao, T.T., Leichter, G., Wei, Y.S., 2012. Countervailing effects of value and risk perceptions in manufacturers' adoption of expensive, discontinuous innovations. Ind. Market. Manag. 41, 659–668.
García-Granero, A., Llopis, Ó., Fernández-Mesa, A., Alegre, J., 2015. Unraveling the link between managerial risk-taking and innovation: the mediating role of a risk-taking climate. J. Bus. Res. 68, 1094–1104.
Ghadim, A.K.A., Pannell, D.J., Burton, M.P., 2005. Risk, uncertainty, and learning in adoption of a crop innovation. Agric. Econ. 33, 1–9. https://doi.org/10.1111/j.1574-0862.2005.00433.x.
Giaccone, S.C., Magnusson, M., 2022. Unveiling the role of risk-taking in innovation: antecedents and effects. R D Manag. 52, 93–107.
Grubisic, V., Ferreira, V., Ogliari, A., Gidel, T., 2011. Recommendations for risk identification method selection according to product design and project management maturity, product innovation degree and project team. In: DS 68-3: Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, vol. 3. Design Organisation and Management, Lyngby/Copenhagen, Denmark, 15.-19.08. 2011.
Gurd, B., Helliar, C., 2017. Looking for leaders: 'Balancing' innovation, risk and management control systems. Br. Account. Rev. 49, 91–102. https://doi.org/10.1016/j.bar.2016.10.008.
Hall, J., Bachor, V., Matos, S., 2014. The impact of stakeholder heterogeneity on risk perceptions in technological innovation. Technovation 34, 410–419.
Hartwig, S., Mathews, S., 2020. Innovation project risk analytics: a preliminary finding. Res. Technol. Manag. 63, 19–23.
Hellström, T., 2003. Systemic innovation and risk: technology assessment and the challenge of responsible innovation. Technol. Soc. 25, 369–384.
Hock-Doepgen, M., Clauss, T., Kraus, S., Cheng, C.F., 2020. Knowledge management capabilities and organizational risk-taking for business model innovation in SMEs. J. Bus. 130, 683–697.
Hoecht, A., Trott, P., 2006. Innovation risks of strategic outsourcing. Technovation 26, 672–681.
Howell, A., 2015. 'Indigenous' innovation with heterogeneous risk and new firm survival in a transitioning Chinese economy. Res. Pol. 44, 1866–1876. https://doi.org/10.1016/j.respol.2015.06.012.
Hrytsenko, L., 2021. Risk-management of Public-Private Partnership Innovation Projects. Marketing I Menedżment Innovacij.
Jen, H.Y., Liu, Y.L., 2012. Project risk evaluation with design of experiment: a case of developing a generic drug analytic method development project. Total Qual. Manag. Bus. Excel. 23, 1171–1189. https://doi.org/10.1080/14783363.2011.637791.
Juraj, N., Mária, M.S., . Risk governance in innovations in mental healthcare services: case study hronovce. Current Trends in Public Sector Research , 320.
Kalvet, T., Lember, V., 2010. Risk management in public procurement for innovation: the case of Nordic–Baltic Sea cities. Innovat. Eur. J. Soc. Sci. Res. 23, 241–262. https://doi.org/10.1080/13511610.2011.553509.
Keizer, J.A., Halman, J.I., 2007. Diagnosing risk in radical innovation projects. Res. Technol. Manag. 50, 30–36.
Keizer, J.A., Halman, J.I., 2009. Risks in major innovation projects, a multiple case study within a world's leading company in the fast moving consumer goods. Int. J. Technol. Manag. 48, 499–517.
Khachaturyan, M.V., Klicheva, E.V., Velikorossov, V., 2019. Features of business process reengineering and possessory risk management in the context of innovation economic development. In: 2019 2nd International Conference on Contemporary Education and Economic Development (CEED 2019). Cep. "Education, Science, Technology, Innovation and Life, p. 1.
Köhler, A.R., Som, C., 2014. Risk preventative innovation strategies for emerging technologies the cases of nano-textiles and smart textiles. Technovation 34, 420–430. https://doi.org/10.1016/j.technovation.2013.07.002.
Kothari, C.R., 2004. Research Methodology: Methods and Techniques. New Age International.
Lebedev, V.V., Deberdeeva, N.A., Farkova, N.A., Korobeinikova, L.S., 2022. Systemic risk management of investments in innovation based on csr. Risks 10, 87.
Lendowski, E., Oldeweme, A., Schewe, G., 2022. Drivers of innovation performance and firm performance: examining the inter-relationship of risk-taking, risk management and open innovation. Int. J. Innovat. Manag. 26, 2250015.
Li, Y., Wang, Y., Wang, L., Xie, J., 2022. Investigating the effects of stakeholder collaboration strategies on risk prevention performance in a digital innovation ecosystem. Ind. Manag. Data Syst. 122, 2045–2071.
Lima Rua, O., Musiello-Neto, F., Arias-Oliva, M., 2022. Linking open innovation and competitive advantage: the roles of corporate risk management and organisational strategy. Baltic J. Manag. 18, 104–121.
Lowman, M., Trott, P., Hoecht, A., Sellam, Z., 2012. Innovation risks of outsourcing in pharmaceutical new product development. Technovation 32, 99–109. https://doi.org/10.1016/j.technovation.2011.11.004.
Luo, J.L., Hu, Z.H., 2015. Risk paradigm and risk evaluation of farmers cooperatives' technology innovation. Econ. Modell. 44, 80–85.
Mastroeni, M., Mittra, J., Tait, J., 2021. Political influences on biotechnology-based innovation for European agriculture: risk-assessment and risk management. Technol. Anal. Strat. Manag. 33, 271–282. https://doi.org/10.1080/09537325.2019.1573983.
Meroño-Cerdán, A.L., López-Nicolás, C., Molina-Castillo, F.J., 2018. Risk aversion, innovation and performance in family firms. Econ. Innovat. N. Technol. 27, 189–203.
Miorando, R.F., Ribeiro, J.L.D., Cortimiglia, M.N., 2014. An economic–probabilistic model for risk analysis in technological innovation projects. Technovation 34, 485–498.
Mohammad, A., Ghwanmeh, S., Alibrahim, A., 2014. Establishing Effective Guidelines to Avoid Failure and Reducing Risk in E-Business 2844.
Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L.A., 2015. Preferred reporting items for systematic review and meta-analysis protocols (prisma-p) 2015 statement. Syst. Rev. 4, 1–9.
Murro, P., 2013. The determinants of innovation: what is the role of risk? Manch. Sch. 81, 293–323.
Nahar, N., Huda, N., Tepandi, J., 2012. Critical risk factors in business model and is innovations of a cloud-based gaming company: case evidence from scandinavia. In: 2012 Proceedings of PICMET'12: Technology Management for Emerging Technologies. IEEE, pp. 3674–3680.
Nechaev, A.S., Ognev, D.V., Antipina, O.V., 2017. Analysis of risk management in innovation activity process. In: 2017 International Conference" Quality Management, Transport and Information Security, Information Technologies"(IT&QM&IS). IEEE, pp. 548–551.

Neumann, M., Bender, B., et al., 2016. Risk-oriented development of innovative products: a model-based approach. In: DS 85-2: Proceedings of NordDesign 2016, vol. 2, pp. 350–359. Trondheim, Norway, 10th-12th August 2016.
Nguyen, T.H., Marmier, F., Gourc, D., 2013. A decision-making tool to maximize chances of meeting project commitments. Int. J. Prod. Econ. 142, 214–224.
Ning, B., Ruoyu, L., 2007. A Framework of Risk Analyzing in Service Innovation, pp. 1–5. https://doi.org/10.1109/ICSSSM.2007.4280156, 2161-1904.
OECD, 2016. Manuel de Frascati 2015: Lignes directrices pour le recueil et la communication des données sur la recherche et le développement expérimental. Organisation for Economic Co-operation and Development, Paris.
Osborne, S., Brandsen, T., Mele, V., Nemec, J., van Genugten, M., Flemig, S., 2020. Risking innovation. Understanding risk and public service innovation—evidence from a four nation study. Publ. Money Manag. 40, 52–62. https://doi.org/10.1080/09540962.2019.1621051.
Paluch, S., Wünderlich, N.V., 2016. Contrasting risk perceptions of technology-based service innovations in inter-organizational settings. J. Bus. Res. 69, 2424–2431. https://doi.org/10.1016/j.jbusres.2016.01.012.
Penide, T., Gourc, D., Pingaud, H., Peillon, P., 2013. Innovative process engineering: a generic model of the innovation process. Int. J. Comput. Integrated Manuf. 26, 183–200.
Puente, J., Gascon, F., Ponte, B., de la Fuente, D., 2019. On strategic choices faced by large pharmaceutical laboratories and their effect on innovation risk under fuzzy conditions. Artif. Intell. Med. 100, 101703. https://doi.org/10.1016/j.artmed.2019.101703.
Qin, L., Kirikkaleli, D., Hou, Y., Miao, X., Tufail, M., 2021. Carbon neutrality target for g7 economies: examining the role of environmental policy, green innovation and composite risk index. J. Environ. Manag. 295, 113119.
Rodríguez, H., 2018. Nanotechnology and risk governance in the European Union: the constitution of safety in highly promoted and contested innovation areas. NanoEthics 12, 5–26.
Roper, S., Tapinos, E., 2016. Taking risks in the face of uncertainty: an exploratory analysis of green innovation. Technol. Forecast. Soc. Change 112, 357–363.
Röth, T., Spieth, P., 2019. The influence of resistance to change on evaluating an innovation project's innovativeness and risk: a sensemaking perspective. J. Bus. Res. 101, 83–92.
Ryman, J.A., Roach, D.C., 2022. Innovation, effectuation, and uncertainty. Innovation 1–21.
Schuhmacher, A., Brieke, C., Gassmann, O., Hinder, M., Hartl, D., 2021. Systematic risk identification and assessment using a new risk map in pharmaceutical r&d. Drug Discov. Today 26, 2786–2793.
Schulte, J., Hallstedt, S., 2018a. Sustainability risk management for product innovation. In: 15th International Design Conference, DESIGN 2018; Dubrovnik, the Design Society, pp. 655–666.
Schulte, J., Hallstedt, S.I., 2018b. Company risk management in light of the sustainability transition. Sustainability 10, 4137.
Shandilya, N., Marcoulaki, E., Barruetabeña, L., Llopis, I.R., Noorlander, C., Jiménez, A.S., Oudart, Y., Puelles, R.C., Pérez-Fernández, M., Falk, A., Resch, S., Sips, A., Fransman, W., 2020. Perspective on a risk-based roadmap towards the implementation of the safe innovation approach for industry. NanoImpact 20, 100258. https://doi.org/10.1016/j.impact.2020.100258.
da Silva Etges, A.P.B., Cortimiglia, M.N., 2019. A systematic review of risk management in innovation-oriented firms. J. Risk Res. 22, 364–381.
Sovacool, B.K., Gilbert, A., Nugent, D., 2014. Risk, innovation, electricity infrastructure and construction cost overruns: testing six hypotheses. Energy 74, 906–917.
Stosic, B., Mihic, M., Milutinovic, R., Isljamovic, S., 2017. Risk identification in product innovation projects: new perspectives and lessons learned. Technol. Anal. Strat. Manag. 29, 133–148.
Su, C.W., Umar, M., Khan, Z., 2021a. Does fiscal decentralization and eco-innovation promote renewable energy consumption? analyzing the role of political risk. Sci. Total Environ. 751, 142220.
Su, Z.W., Umar, M., Kirikkaleli, D., Adebayo, T.S., 2021b. Role of political risk to achieve carbon neutrality: evidence from Brazil. J. Environ. Manag. 298, 113463.
Subramanian, V., Semenzin, E., Hristozov, D., Zabeo, A., Malsch, I., McAlea, E., Murphy, F., Mullins, M., van Harmelen, T., Ligthart, T., et al., 2016. Sustainable nanotechnology decision support system: bridging risk management, sustainable innovation and risk governance. J. Nanoparticle Res. 18, 89.
Sun, Y., Bi, K., Yin, S., 2020a. Measuring and integrating risk management into green innovation practices for green manufacturing under the global value chain. Sustainability 12, 545.
Sun, Y., Wu, L., Yin, S., 2020b. Green innovation risk identification of the manufacturing industry under global value chain based on grounded theory. Sustainability 12, 10270.
Suprin, M., Chow, A., Pillwein, M., Rowe, J., Ryan, M., Rygiel-Zbikowska, B., Wilson, K.J., Tomlin, I., 2019. Quality risk management framework: guidance for successful implementation of risk management in clinical development. Therapeutic innovation & regulatory science 53, 36–44.
Torelli, R., Balluchi, F., Furlotti, K., 2019. The Materiality Assessment and Stakeholder Engagement: A Content Analysis of Sustainability Reports. https://doi.org/10.31219/osf.io/tw6c7.
Torugsa, N.A., Arundel, A., 2017. Rethinking the effect of risk aversion on the benefits of service innovations in public administration agencies. Res. Pol. 46, 900–910. https://doi.org/10.1016/j.respol.2017.03.009.
Usai, A., Scuotto, V., Murray, A., Fiano, F., Dezi, L., 2018. Do entrepreneurial knowledge and innovative attitude overcome "imperfections" in the innovation process? Insights from SMEs in the UK and Italy. J. Knowl. Manag. 22, 1637–1654.
Wang, J., Lin, W., Huang, Y.H., 2010. A performance-oriented risk management framework for innovative r&d projects. Technovation 30, 601–611.
Wang, L., Bi, X., 2021. Risk assessment of knowledge fusion in an innovation ecosystem based on a ga-bp neural network. Cognit. Syst. Res. 66, 201–210.
Whyles, G., Van Meerveld, H., Nauta, J., 2015. Forward commitment procurement: a practical methodology that helps to manage risk in procuring innovative goods and services. Innovat. Eur. J. Soc. Sci. Res. 28, 293–311.
Wu, D.D., Kefan, X., Hua, L., Shi, Z., Olson, D.L., 2010. Modeling technological innovation risks of an entrepreneurial team using system dynamics: an agent-based perspective. Technol. Forecast. Soc. Change 77, 857–869.
Wu, J., Wu, Z., 2014. Integrated risk management and product innovation in China: the moderating role of board of directors. Technovation 34, 466–476. https://doi.org/10.1016/j.technovation.2013.11.006.
Xu, L., Tang, S., 2017. Technology innovation-oriented complex product systems r&d investment and financing risk management: an integrated review. In: Proceedings of the Tenth International Conference on Management Science and Engineering Management. Springer, pp. 1653–1663.
Yan, X., Zhang, Y., Pei, L.L., 2021. The impact of risk-taking level on green technology innovation: evidence from energy-intensive listed companies in China. J. Clean. Prod. 281, 124685.
Yang, Y., 2008. Technology innovation and risks in outsourcing. In: 2008 International Conference on Risk Management & Engineering Management. IEEE, pp. 416–421.
Zhang, B., Ma, L., Liu, Z., Wang, P., 2019. Sustainable technology innovation path recognition: an evaluation of patent risk of international trade. Sustainability 11, 5002.
Zhao, W., Yang, T., Hughes, K.D., Li, Y., 2021. Entrepreneurial alertness and business model innovation: the role of entrepreneurial learning and risk perception. Int. Enterpren. Manag. J. 17, 839–864.
Zhou, B., Li, Y.m., Sun, F.c., Zhou, Z.g., 2021. Executive compensation incentives, risk level and corporate innovation. Emerg. Mark. Rev. 47, 100798.