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DEVELOPMENT OF NOVEL METHODS AND TOOLS TO SUPPORT TECHNOLOGY TRANSFER IN ACADEMIA

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Abstract

In recent years, technology transfer of academic knowledge to industry has increased significantly. However, in many cases, collaboration between academia and industry is struggling to establish due to differences in views, objectives and organisational issues.

Several approaches to support technology transfer have been developed, especially within the industrial context, exploring almost all its characteristic dynamics. Far less effort has been spent, however, on exploring how technology transfer can manifest itself when the academia is also involved.

This dissertation addresses the typical problems of an academic Technology Transfer Office, proposing methodological and organisational solutions to overcome them. This method is the result of the systematic classification and analysis of different technology transfer experiences that the candidate has faced during three years of work at the Technology Transfer Office of the University of Bergamo. In this context, the candidate has studied the most innovative tools and strategies with which a TTO can retrieve both technical and market knowledge and how this information can be included in a range of services that this office can offer to its faculty.

The candidate was concerned to understand how new Information retrieval tools may impact on the main services offered by TTOs: technology scouting, checking intellectual property requirements, matchmaking with stakeholders, creation of the proof of concept and commercial exploitation of the idea.

The main novelty of this work consists in the exploitation of Information retrieval techniques based on semantics and artificial intelligence. These technologies, which are increasingly widespread today, have made giant strides forward and offer important possibilities for the enhancement of services related to the retrieval of knowledge from documentary sources. The proposed method has explored these techniques and identified those that are most suitable for the specific purposes of a TTO. In particular, it will show some useful results for product analysis such as automatic identification of functions, identification of scope, or requirements. From this information it is then possible to widen the scope of the search to market information in a more targeted and precise way than is normally done with more traditional tools.

In particular, the method consists of an initial Information retrieval phase, by automatically extracting information from the texts of patents and scientific papers describing similar products based on a similar functioning. The automatic extraction of information is carried out through the use of text-mining tools that have been specially customised, introducing new dependency patterns. The adoption of these algorithms on large document corpora was possible thanks to the combination of different IT tools, some still experimental, and the contribution of Spin-offs of the University of Bergamo (Bigflo Srl and Trix Srl), which supported the technical implementation.

Another main pillar of this dissertation relates to the estimation of market opportunities for a given product developed during university research. Although the state of the art is rich in examples, methods, tools and databases available to perform this task, there are still many open problems and inefficiencies. The fact of having advanced knowledge retrieval techniques for problem solving and requirements definition offers interesting ideas for an innovative proposal also in the field of business evaluation. The same techniques can be exploited for a different purpose, market positioning, and more generally business evaluation. The same patent information can be integrated with other more conventional sources to increase the depth of judgement and level of analysis. On this topic, this dissertation explains how semantic tools can be used, what procedures can be put in place to improve the efficiency of analysis, and how results can be communicated in a concise and easy-to-read form for teachers and researchers who are not necessarily experts in the field of business.

The application of the proposed method has been exemplified with a real case study related to the estimation of the potential of the market introduction of a heating fabric constituted of carbon fibre filaments. The reference competitor product that has been considered is instead a heating fabric constituted of copper fibre.

The results obtained in this case study, combined with those of two other case studies that were addressed by the candidate at the Technology Transfer Office, are reported and discussed in detail. These two case studies concern water-repellent textile coatings made of SOL-GEL and photocatalytic ceramic foams for the removal of micro pollutants. Several advantages of the proposed method emerged in comparison with other supporting methods. A larger number of documentary sources, even those formatted in a rawer way can be analysed. Expert involvement is limited due to the method's ability to discriminate relevant results with high precision and recall, even when the analysed documents are loosely filtered. The expert's judgement is objectivised as it is based on predetermined requirements which are extracted semi-automatically. Finally, the addition of economic considerations makes it possible to assess technology transfer in a broader way, without being limited only to technical considerations gathered by interviewing researchers.

Riassunto

Negli ultimi anni, il trasferimento tecnologico della conoscenza accademica verso l'industria è notevolmente aumentato. Tuttavia, in molti casi, la collaborazione tra accademia ed industria fatica ad affermarsi per divergenze di vedute, obiettivi e questioni organizzative.

Diversi approcci per supportare il trasferimento tecnologico sono stati sviluppati, soprattutto all'interno del contesto industriale, esplorando le sue principali dinamiche. Decisamente minori sforzi sono stati spesi, invece, per esplorare come il trasferimento tecnologico si può manifestare quando anche l'accademia è coinvolta.

Questa tesi affronta le problematiche tipiche di un Ufficio di Trasferimento Tecnologico accademico proponendo delle soluzioni a livello metodologico e organizzativo per superarle. Tale metodo è il risultato della classificazione e analisi sistematiche di diverse esperienze di trasferimento tecnologico che il candidato ha affrontato durante tre anni di lavoro presso l'Ufficio di Trasferimento Tecnologico dell'Università degli studi di Bergamo. In tale contesto, il candidato ha studiato gli strumenti e le strategie più innovative con cui un TTO può recuperare conoscenza sia tecnica sia di mercato e come queste informazioni possano essere inserite in un ventaglio di servizi che tale ufficio può offrire ai propri docenti.

Il candidato si è preoccupato di comprendere come i nuovi strumenti per il recupero delle informazioni possano impattare sui principali servizi offerti dai TTO: scouting tecnologico, analisi dei requisiti brevettuali, matchmaking con stakeholders, creazione del proof of concept e valorizzazione commerciale dell'idea.

La novità principale di questo lavoro consiste nello sfruttamento di tecniche di ricerca di informazioni (Information retrieval) basate sulla semantica e l'intelligenza artificiale. Queste tecnologie, oggi sempre più diffuse, hanno fatto passi avanti giganteschi e offrono possibilità importanti per il rafforzamento di servizi legati al recupero della conoscenza da fonti documentali. Il metodo proposto ha esplorato queste tecniche e individuato quelle che maggiormente si prestano agli scopi specifici di un TTO. In particolare, verranno mostrati alcuni risultati utili all'analisi di prodotto quali l'identificazione automatica delle funzioni, l'identificazione del campo di applicazione, o dei requisiti. Da

queste informazioni è possibile poi allargare il campo della ricerca ad informazioni sul mercato in modo più mirato e preciso di quanto normalmente venga fatto con gli strumenti più tradizionali.

In particolare, il metodo consta di una prima fase relativa all'Information retrieval, estraendo automaticamente le informazioni dai testi di brevetti e articoli scientifici che descrivono prodotti simili e basati su un funzionamento analogo. L'estrazione automatica delle informazioni è effettuata mediante l'utilizzo di strumenti di text-mining che sono stati appositamente customizzati, introducendo nuovi dependency patterns. L'adozione di questi algoritmi su grandi corpora documentale è stata possibile grazie alla combinazione di diverso strumenti informatici, alcuni ancora sperimentali, e al contributo di Spin-off dell'Università degli studi di Bergamo (Bigflo Srl e Trix Srl), che hanno supportato l'implementazione tecnica.

Un 'altra colonna portante di questa tesi è relativa alla stima delle opportunità di mercato per un dato prodotto sviluppato durante le ricerche universitarie. Sebbene lo stato dell'arte sia ricco di esempi, metodi, strumenti e banche dati a disposizione per svolgere questo compito, ci sono ancora molti problemi aperti e inefficienze. Il fatto di disporre di tecniche avanzati per il recupero della conoscenza per il Problem solving e per la definizione dei requisiti offre degli spunti interessanti per una proposta innovativa anche nel campo della Business evaluation. Le stesse tecniche possono essere sfruttate per uno scopo diverso, il posizionamento di mercato, e più in generale la valutazione del business. Le stesse informazioni brevettuali possono essere integrate con altre fonti più convenzionali per aumentare la profondità di giudizio e il livello di analisi. Su questo tema, in questa tesi, viene spiegato come si possono usare gli strumenti semantici, quali procedure possono essere messe in atto per migliorare l'efficienza delle analisi e in che modo si possono comunicare i risultati in forma concisa e di semplice lettura per docenti e ricercatori non necessariamente esperti nel campo dell'imprenditoria.

L'applicazione del metodo proposto è stata esemplificata con un reale caso studio relativo alla stima delle potenzialità dell'introduzione sul mercato di un tessuto riscaldante costituito da filamenti in fibra di carbonio. Il prodotto concorrente di riferimento che è stato considerato è invece un tessuto riscaldante in fibra di rame.

I risultati ottenuti in questo caso studio, sono stati combinati con quelli di altri due casi significativi che sono stati a loro volta selezionati dal set più ampio di tutti quelli affrontati dal candidato presso il TTO. Tali risultati sono stati riportati e discussi nel dettaglio. Questi due casi studio riguardano rivestimenti tessili idrorepellenti in SOL-GEL e schiume ceramiche fotocatalitiche per la rimozione di microinquinanti. Diversi vantaggi del metodo proposto sono emersi confrontandolo con altri metodi a supporto. Un maggior numero di fonti documentali, anche formattate in modo più grezzo possono essere analizzate. Il coinvolgimento dell'esperto è limitato grazie alla capacità del metodo di discriminare risultati pertinenti con alte precision e recall, anche quando i documenti analizzati sono filtrati in modo approssimativo. Il giudizio dell'esperto nella valutazione è oggettivato in quanto basato su requisiti predeterminati che sono estratti in modo semi-automatico. Infine, l'aggiunta di considerazioni economiche permette di valutare il trasferimento tecnologico in modo più ampio, senza limitarsi solamente a considerazioni tecniche raccolte colloquiando con i ricercatori.

1. Introduction

In this Section of the dissertation, the purposes of the research, the context as well as scientific background and the candidate personal experience are introduced and explained.

In extreme synthesis, the introductory Section consists in three main steps. Section 1.1 introduced and motivates the purposes of the research by briefly outlining the international and national context, presenting the main limitations of methods and tools and addressing the main novelties of the proposed research. Section 1.2 provides a general overview concerning the topics discussed and by presenting definitions from the literature. Section 1.3 refers to the candidate personal experience and the operative activities conducted during the PhD period.

1.1. Purposes of the research

Technology transfer is strategically important for the valorisation of project ideas in industry. In the United States, more than 200 types of vaccines have been developed since 1990 through public-private partnership and over 865 billion of dollars contributed to United States gross domestic product from 1996 to 2020, as stated by Stanford University annual report. The globalization of the economy and the interconnectedness of people have made a fundamental contribution in this regard. Currently, the academia is also relying extensively on technology transfer. As reflected in the most recent reports published by AUTM, the leading association in technology transfer, in 2020, the United States invested over 71 billion dollars to strengthen the process of technology transfer in the academia against approximately three billion dollars in revenues generated from the licensing or assignment of academic inventions to the market.

In Italy, since the early 2000s, academia has started a process of “commercialising their research” in order to act as the country's innovation engine, transferring results, projects and knowledge to society and the market so that value can be generated. Technology transfer has therefore become an integrated part of academia together with education and research. Many of them have therefore established dedicated offices. Data from the latest Netval reports, the Italian network for the valorisation of research, revealed a partial positive increase in all the indicators relating to technology transfer, a sign of the academia' interest in these issues, but also a strong heterogeneity among national academia.

One of the problems is the lack of shared guidelines to standardise the way technology transfer offices in universities operate. To mitigate this problem, the measures that have been put in place by individual academia and by associations that involve academia and research centres, such as Netval, have been: providing education courses to introduce a shared terminology on technology transfer; raising awareness of technology transfer, also by learning from foreign models; introducing support tools such as patent and scientific paper databases; introducing dedicated funding for the most virtuous academia in technology transfer; recruiting new professional figures specialised in entrepreneurship and patentability support.

During the PhD research period, the author of this dissertation had the opportunity to personally experience some of these problems by working at the Technology Transfer Office (TTO) of the University of Bergamo. The work agreement was co-financed by the Italian Ministry of Economic Development through the General Directorate for the Protection of Industrial Property - Italian Patent and Trademark Office. The scientific support for the writing of the dissertation came from the author collaboration with the Virtualization and Knowledge research group of the department of Management, Information and Production Engineering at the University of Bergamo, which also deals with extracting knowledge from documentary sources such as patents.

The problem addressed by this dissertation concerns the need to support technology transfer with dedicated methods and tools, facilitating its phases, reducing time and costs and engaging the different actors involved on common strategies and objectives.

By means of a rigorous analysis of how technology transfer has been approached in the literature (see Section 2.1.1 and Section 2.1.2) and at the TTO of the University of Bergamo (see Section 3.2) the main supporting methods and tools have been identified and analysed. At the same time, also their main limitations have been identified and reported in the same Section.

Such limitations are as follows. The time and cost burden of the analysis of related documentary sources due to the excessive involvement of manual activities. Subjectivity in the research and evaluation of product application fields is almost always delegated to the knowledge and intuition of experts. The difficulty in selecting relevant documents requiring expert involvement and/or extensive time resources. The information useful for the technology transfer is not classified according to a reference ontology, consequently generating confusion during the assessments provided by different professional figures. The lack of flexibility in the text formats of the documents that are analysed from a linguistic and formatting point of view. Frequently unacceptable values of recall and precision of information useful for technology transfer that are automatically extracted by text-mining methods and tools.

To overcome these limitations, this dissertation introduced a novel method aimed to support technology transfer. The method consists of two main steps and several sub-steps. The first step deals with a semi-automatic procedure for Information retrieval to collect the main Functions, Application fields and requirements of a given product, starting from a selected pool of documentary sources. In the second step, the product is evaluated and compared to a concurrent one. The basis of the evaluation is constituted by the Market potential, involving the experts' opinions, and the Economic potential involving patent cost and the incomes deriving from similar technologies.

The main novelties of the proposed method are:

- The analysis of a larger number of documentary sources, even of the order of thousands of documents, which do not require any prior preliminary formatting requirements.
- The exclusion of the involvement of experts to construct and pre-process the pool of documents to be analysed. This is due to the method's ability to successfully discriminate relevant results even within vast document sources characterised by extensive background noise.
- The increased accuracy of the method in collecting relevant information, due to the introduction of dependency patterns, compared to other methods such as those based on Subject Action Object triads.
- The greater objectification in the evaluation of the product's market potential during the involvement of experts. This is possible because the expert is supported

by requirements extracted semi-automatically from documentary sources during his or her evaluation.

- The integration of economic considerations in the evaluation of technology transfer allows for a broader evaluation of the product than just the technical considerations that typically emerge from the interview with researchers. This broadened perspective was in fact particularly appreciated during the interviews with entrepreneurs.

The proposed method is mainly addressed to the different parties involved in technology transfer. For a researcher who has developed an innovative product, the proposed method may be useful to increase her/his awareness of its potential (Functions and fields of application). In this way it is possible to intervene in the writing of a patent by enriching it with strategic details typically required by examiners as well as in the writing of projects to participate in funding calls. At the same time, the proposed method could also be useful for a professional involved in technology transfer to identify sectors that might be interested in the possible applications resulting from the product. In this way, the technology transfer professional can understand which companies address in order to enhance the value of the product. Furthermore, the proposed method could also be useful for entrepreneurs to assess the market and economic potential of the product with a view to investing in it at the expense of other options. Finally, the proposed method could also be useful to the researcher studying methods to support technology transfer, by introducing a partly new perspective to do Information retrieval and combining market and economic analysis in a novel manner in the field of technology transfer.

This dissertation is structured as follows.

Section 2 is dedicated to the State of the Art. Its first part presents an introduction about the concept of technology transfer by referring to the definitions from the literature. In the second part of this Section, a literature review about the method and tools for supporting technology transfer is presented. The methods studied were classified into two parts: the Information retrieval part to collect and manage knowledge from documentary sources and the Business evaluation part aimed at assessing the economic viability of a product or technology transfer process. For both Information retrieval and Business evaluation, the main open problems and limitations from the literature are presented.

Section 3 presents an introduction about the concept of technology transfer at a practical level, by referring to the activities of the TTO of the University of Bergamo where the candidate worked during the PhD period and by presenting the main open problems and limitations, gathered from the practical experience at the TTO.

Section 4 introduces and describe the method proposed in this dissertation to overcome the identified open problems and limitations at the State of the Art concerning Information retrieval. This Section is articulated into four main steps, following the structure of the proposed method. The first one deals with the collection of documentary sources, while the others with the identification and analysis of the Functions, applications and requirements from the text.

Section 5 reports the results of an exemplary case study in which the proposed method concerning Information retrieval was applied to support the technology transfer of heating fabric consisting of carbon fibre filaments.

Section 6 introduces and describe the method proposed in this dissertation to overcome the identified open problems and limitations at the State of the Art concerning Business evaluation. This Section is articulated into three main steps, following the structure of the proposed method. The first one deals with Market potential analysis, the second ones provides an Economic evaluation and, in the end, the third ones provides a novel tool of comparison about the Market and Economic evaluations.

Section 7 reports the results of an exemplary case study in which the proposed method concerning Business evaluation was applied to support the technology transfer of heating fabric consisting of carbon fibre filaments.

Section 8 discusses the results of the case study in comparison with other applications followed by the candidate, the possible implications of the proposed method in technology transfer related activities and the future developments.

Section 9 draws the conclusions.

1.2. What is technology transfer and definitions from literature

Technology transfer may be carried out in two directions, as an inward or an outward process.

The inward process consists of acquiring external emerging technologies and it is also called Inward technology transfer (e.g. Rush et al., 2007; Savioz and Blum, 2002).

The outward process may appear under various names: white space opportunity (Porter and Detampel, 1995), business opportunities, Technology Opportunity Discovery (Yoon et al., 2014). In literature, Outward Technology Transfer (OTT) often refers to the company's asset and intellectual property management strategy. For Lichtenthaler (Lichtenthaler, 2008), OTT is the process by which companies commercialize their technology assets externally exploiting technology for their own products and services, often by means of out licensing. Jeon et al., (2011) proposes a very similar definition based on the same paradigm; according to Jeon, OTT is the process by which companies trade their intellectual properties to identify new potential fields of application to market internally developed technologies, transferring their knowledge and technologies into new products.

For the sake of simplicity, in this study it will be adopted a definition that does not take into account management aspects, while the focus is on technology transfer to the outside world, that is to say the possibility of innovating a product already on the market by replacing new technology with an existing one. In turn, technology transfer offices can largely be classified into two types: one relates to anticipating new technologies and products that have not yet been developed or are still emerging (Daim et al., 2006), thus finding itself a Blue ocean: a market space still unexplored and without competition (Kim and Mauborgne, 2014); the other relates to new markets that can be created or exploited by utilizing the technology that a firm currently possesses (e.g. Yoon et al., 2014; Park et al., 2013b).

In both cases, most companies face major management difficulties in leveraging this type of technology transfer paradigm. In fact, it is not enough to have a valid and better technology than the competition, but you need to be able to rethink your business models (Borgianni et al., 2012) and to properly manage licenses (Lichtenthaler, 2008). The analysis of the importance of the role of licenses for OTT of corporate intellectual property is at the heart of a great deal of literature (Kutty and Chakravarty, 2011), while other authors, on the other hand, are concerned with understanding the set of conditions to carried out to make this process effective (Schlie et al., 1987), or the right balancing between Inward and Outward Technology Transfer in open innovation paradigm.

Before innovation can be managed, however, there is a need of a much more concrete step, which consists of identifying all potential areas of business compatible with the given technology. To date, the greatest number of cases of OTT probably resides in the knowledge of an expert and personal intuition, and a method as automatic as possible would be needed to indicate to an entrepreneur what products are nowadays on the market that could host the technology he developed.

It is now widely acknowledged that in recent years' universities are embracing a third mission in addition to education and research: to contribute to economic development, thus becoming "business academia". The same applies to the main public research organisations that have invested efforts and resources in technology transfer. The reasons for this change are to be found in a number of institutional and contextual factors, including:

- the decreasing and changing nature of research funding, which is becoming increasingly mission-oriented and performance-based (Secundo et al., 2017).
- An increase in the demand for research that is industrially and economically relevant, i.e. that can contribute more directly to the development of the national economy (e.g. Geoghegan et al., 2008; Tijssen, 2006).
- The internationalisation of research, which increases the pressure on universities and public research bodies to compete and supports a greater focus on specialisation (e.g. Knudsen et al., 2021; Secundo et al., 2017).
- An increase in the outsourcing of research activities by both large companies, including multinationals, and small and medium-sized enterprises through the creation of clusters and/or industrial districts (e.g. Knudsen et al., 2021; Nicotra et al., 2021).
- The increase in the number and relevance of opportunities for commercial exploitation (Nicotra et al., 2021).

This model of the “entrepreneurial academia” has focused attention on the problem of the industrial and commercial exploitation of the technologies produced by the academia's research activities, in order to gain both economic and image benefits.

Academia are entering the economic context as active players in the market for the generation of knowledge and, in order to carry out this role, they must equip themselves with structures dedicated to the management of technology transfer: the Technology Transfer Offices (TTO).

The literature developed to date on the organisation of technology transfer largely takes into account the American model, which is characterised by uniformity in the role and activities/processes carried out by TTOs to foster the transfer of knowledge and technology from universities/public research organisations to enterprises. (Etzkowitz, and Goktepe, 2005).

Without necessarily taking the American situation as a reference model, which is too distant from the Italian situation because the exogenous or contextual variables are too different (legislation, industrial and financial fabric, public financing system, management of research and intellectual property, etc.), it is important to emphasise the commonality of the strategic and methodological approach to technology transfer in the university sphere, as understood and practised in Italy: "the valorisation of the results of public research, possibly protected by the various forms of privative rights, from inside to outside through the processes of licensing and/or the creation of new businesses" (Conti et al., 2012).

As a result, the technology transfer processes carried out by these offices focus on industrial property protection, licensing and spin-offs, which are seen as the most suitable activities for promoting the industrial and commercial exploitation of the results of the research of academia.

TTO is therefore the structure that mainly deals with the management and transfer of intellectual property belonging to the university in which or for which it works. The TTO plays a key role in the relationship between public research and the market, preparing the ground for the management of all activities aimed at protecting and exploiting the research output.

After having clarified the specific position of the TTO in the complex process of technology transfer it is not so easy to define in a simple and univocal way the name or label that each public research organisation or academia gives to its TTO. From a simple web search it is possible to identify different names given to structures identical or similar to the TTO: (Industrial) Liaison Office; Knowledge Transfer Office; University Industry Linkage; Contract Office; Office of sponsored research; Patenting and Licensing Office; Business Development Office; Office of Technology Licensing.

In fact, many of these structures have the same objectives and carry out the same processes, but from their mere name it is possible to guess the emphasis in terms of both strategic direction and operational activities of the TTO.

From an operational and process planning point of view, some phases or potential lines of development of the activities managed by the TTO can be distinguished: (1) patent culture; (2) patent selection and new business creation; (3) research monitoring and agreements with industry, valorisation through licensing; (4) intellectual property management in the various forms of cooperative research; (5) growth of spin-off companies and access to venture capital; (6) service diversification, new organisational forms of the TTO, new business models for intellectual property management (Kreiling and Bounfour, 2020).

Obviously, a more focused mission guiding the TTO towards a specialisation of a process and/or a different emphasis on certain objectives and activities might change the path described above. Furthermore, the identified phases need not necessarily be sequential, although emphasis should be placed on the considerable level of preparatory work between them.

Regarding the first activity: the patent culture, the TTO is fully committed to informing and involving the internal staff of the public research organisation or academia towards a more conscious and responsible management of their research results. It is essential to disseminate the basic notions of IP protection and valorisation and to establish a relationship of trust and collaboration between TTO managers and researchers.

Starting from basic concepts, it is essential to clarify the correct point of view regarding the patent instrument: it is precisely a transfer instrument and not an objective and/or result for a researcher. This activity will be fundamental for the subsequent development of agreements, contracts and clauses for the management and exploitation of intellectual property in the various forms of cooperative research but also in the creation of new businesses. This will make it easier to identify the correct parameters for the evaluation and selection of inventions to be protected and exploited (Balderi et al., 2010).

In the second activity: patent selection and new business creation, the TTO starts the actual management of the patent portfolio and the first spin-off companies. They are no longer isolated cases to be managed but the processes must become more planned and the activities more professional. Particular mention should be made of the process of selecting but also exploiting both patentable inventions and spin-off companies. TTOs therefore start to equip themselves with resources and competences to follow the creation process of new companies, preferably from protected research results, adopting different strategic approaches. While some TTOs may only offer support for the early stages of the process, others may aim to cover all stages, from research, to formulation of the business idea, incubation and start-up, and even choose to enter the capital of the spin-off company (Huyghe et al., 2014).

In the third activity, research monitoring and agreements with industry and valorisation through licensing, programmes and tools are developed for monitoring research results and selecting patentable inventions, but also from a commercial point of view, strategies and procedures for exploitation (licensing or out-licensing) are better defined.

The fourth activity, intellectual property management in the various forms of cooperative research, underlies an evolution of the patent protection and exploitation strategy. The patent instrument is used and addressed in the search for different forms of cooperation for research (Huyghe et al., 2014), development and industrialisation activities rather than as a first source of generating direct economic returns (Balderi et al., 2010). In this, the first mission of TTOs needs to be defined at the governance level of the public research organisation: to generate economic returns (aiming at self-financing of the TTO) or to foster research returns for the public research organisation. Obviously, the two are not antithetical, but it is necessary to focus efforts in one primary direction to make the system efficient as well as effective (e.g. Kreiling and Bounfour, 2020; Conti et al., 2012).

In the fifth activity, growth of spin-off companies and access to venture capital, the phenomenon of spin-off company creation is no longer spontaneous and sporadic. On the one hand, it is necessary to develop a set of policies related to the investment and disinvestment of the academia in the share capital of spin-off companies, but also to the conflict of interest and competition of research staff involved in the start-up phase of the spin-off company. On the other hand, spin-off companies need to be selected and supported in their growth phase (Conti and Gaule, 2011).

Finally, in the sixth activity, service diversification, new organisational forms of the TTO, new business models for intellectual property management, all the various forms of privatisation for the protection of research results (copyright for software, trademarks, models and industrial designs, etc.) but also the different organisational forms of management of macro-processes (Conti and Gaule, 2011) or individual process activities must be assessed (Giuri et al., 2014). Some empirical evidence points to a trend in Europe of partial outsourcing of certain activities, such as marketing or licensing negotiations, depending on the type of patents in the portfolio and its critical mass and the possibility of drawing on specific expertise within universities.

In Figure 1, the role and positioning of a TTO within a technology transfer process and the interactions with the different parties involved is outlined.

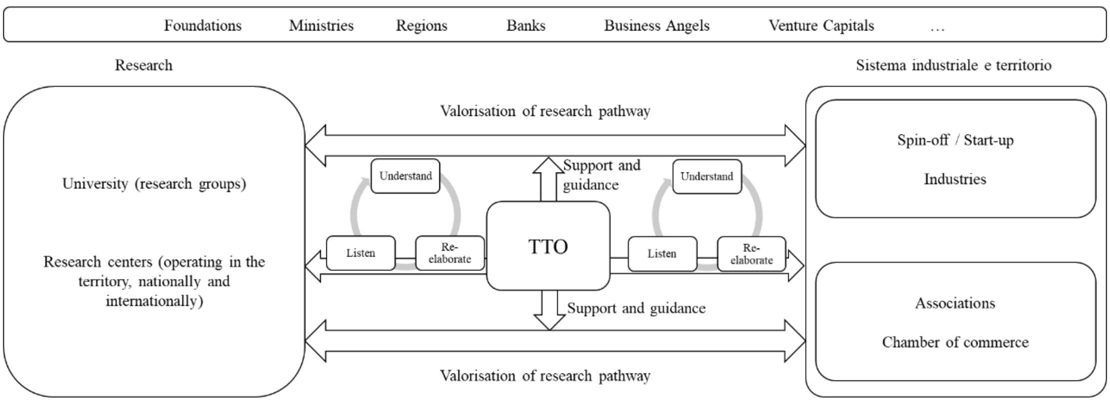


Figure 1. Role and positioning of the TTO in the technology transfer process.

1.3. Candidate personal experience

TTO of the University of Bergamo is part of the Research and Third Mission Service. The Service consists of two Offices, one functional to scientific research, the other to third mission activities, in which the TTO is located. In turn, the academia's third mission is divided into two areas: the enhancement of research and the production of public goods of a social, educational and cultural nature. In order to address these two areas, which are heterogeneous but hinged on the same organisational structure, the Knowledge Transfer Office was created in 2018, also reporting to the Research and Third Mission Service.

From an organisational point of view, the TTO is divided into three main areas:

- Intellectual property management and spin-offs/start-ups - its main mission is to exploit the results of scientific and technological research through legal protection (patents, know-how, trademarks) and their subsequent technology transfer through agreements with public and/or private partners, as well as through the creation of spin-off companies and the accreditation of academia-based start-ups.
- Partnership agreements and forms of association - has as its main mission the negotiation and conclusion of framework agreements, contracts and conventions for scientific collaboration and technology transfer activities, and supports departmental structures on the same issues.
- Public engagement - has as its main mission to support teachers and researchers in the organisation and implementation of public engagement activities.

The role of the TTO is actually much broader than that of service to departments, since it acts as a reference point for an innovation value chain that involves various players in the world of territorial innovation (e.g. science parks, business associations, digital innovation hubs): science parks, business associations, digital innovation hubs), acting as an intermediary for the territory with ecosystems and players operating on a regional/national scale (including the partnership with Warrant Innovation Lab and the establishment of the University for Innovation Foundation (U4I) as well as participation in Technology Clusters and Competence Centres) and internationally (through the China-Italy Technology Transfer Center and the China-Italy Lab on Advanced Manufacturing, initiatives in which the University of Bergamo is a founding partner, and collaboration with Harvard University on Smart Cities issues).

Being part of an innovation chain also allows the TTO to indirectly expand its scope of action, which, given the public nature of the academia, would severely limit the potential and ability to exploit the University of Bergamo's research.

At the TTO, the candidate worked in the research exploitation area, dealing with issues related to the management and protection of intellectual property: promotion of the protection and exploitation of research results through patenting and specific training courses. In order to carry out these activities, it was essential to strengthen training and idea scouting initiatives at academia research groups by creating supply chain actions with research centres, science and technology parks, and public and private bodies.

In order to enhance the value of research results, and to innovate and strengthen procedures and tools for the transfer of skills, knowledge and technologies, a model has been developed to underpin the management component, divided into five evolutionary stages with decision-making gates identified between each stage. This model allows a shift from a reactive to a proactive logic, facilitating the meeting between the demand for innovation coming from the local industrial fabric and the scientific supply of academia research groups.

The definition of this model is the result of the work of the TTO, to which the candidate contributed to reasoning on objectives and defining the flow of activities, imprinting it with a proactive logic to generate a virtuous cycle between internal (researchers) and external stakeholders.

This model allows a shift from a reactive to a proactive logic, facilitating the meeting between the demand for innovation coming from the local industrial fabric and the scientific supply of academia research groups. The model is divided into five phases, which are summarised below:

1. **Technology scouting and screening:** in this phase, recurring technology scouting and screening activities concerning research projects are envisaged through constant interaction with the research groups operating in the University of Bergamo laboratories. The scouting activity requires a strong awareness-raising action by listening, comparing and collecting new ideas and is aimed at accompanying researchers in the creation of the project by highlighting the preliminary potential and the characteristics of the industrial approach.
2. **Protection of intellectual property:** At this phase, the necessary and sufficient requirements for the validity of the intellectual property protection are verified.

By establishing an ongoing relationship with the search team, prior art search and invention originality verification analyses are carried out.

3. **Matchmaking with stakeholder:** in this phase, companies with business interests that are compatible with the solutions offered by academia research are identified. The objective of this phase is the definition of a list of companies to be submitted to the project contact person. The involvement of companies is done directly, through ad hoc invitations or the organisation of matchmaking events (in person or remotely) where researchers present their activities to an audience of company representatives invited on the basis of mutual interests. This phase may lead to the signature of a bilateral confidentiality agreement, the definition of a letter of intent or the drafting of a contract. The candidate was supported in this phase by a company experienced in access to credit called Warrant Innovation Lab.
4. **Creation of the proof of concept:** In this phase, feedback is gathered from all those involved in the project, thus mitigating the risk of unforeseen events. The support offered to project proposers is twofold: technical, through actions aimed at raising the level of technological maturity of the proposal; economic, through funding to verify commercial feasibility, carry out scale-up tests, build/improve prototypes, overcome gaps that may hinder attractiveness to investors and test the basic functionalities and principles of the project.
5. **Commercial exploitation:** in this phase, the intangible idea is transformed into an economic and/or social payoff and is adequately regulated in order to promote its commercial viability. In essence, the “exit point” of the accompaniment process is formalised. The objectives of this phase concern the drafting of a business plan with an operational plan and possible time-to-market, implementation of any licensing/discipline/protection instruments, and concluding with an economic evaluation.

The five phases of the model: technology scouting and screening, protection of intellectual property, matchmaking with stakeholder, creation of the proof of concept, and commercialization exploitation are presented in the Figure 2.

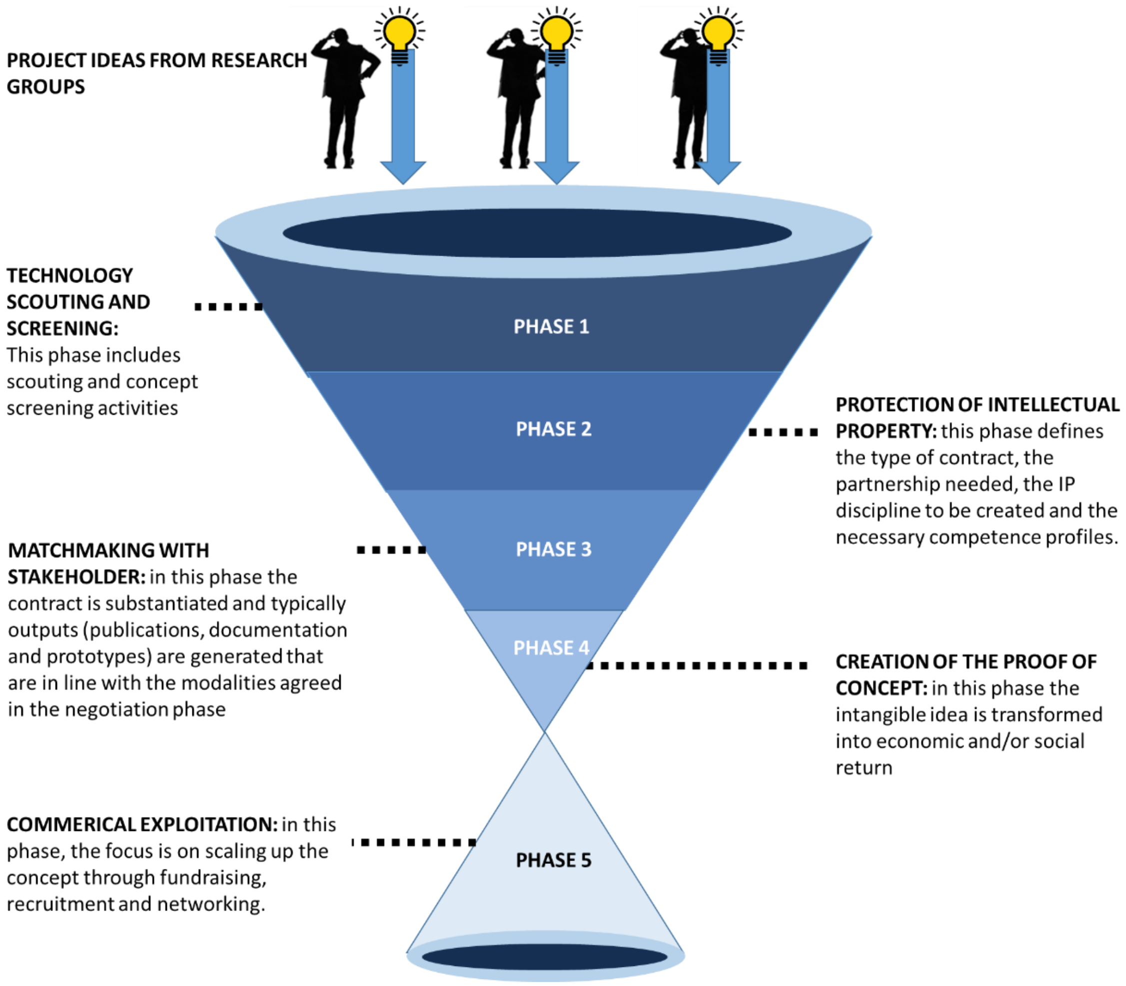


Figure 2. Five-step model of research enhancement adopted by the TTO of the University of Bergamo.

The candidate's employment at the TTO was co-financed by the Italian Ministry of Economic Development through the Directorate General for the Protection of Industrial Property - Italian Patent and Trademark Office, through a call for funding of a project aimed at strengthening and capacity building of TTOs of Italian academia.

The allocation of financial resources by the Ministry is part of one of the first national experiences in the field of technology transfer with the prerogative of increasing the intensity of technology transfer flows to the business system. Sixty-five projects submitted by Italian universities have been funded.

Through the implementation of these projects, significant results have been achieved in terms of meetings, contacts and contracts with companies, new patents, new licensing contracts, and so forth. Through this measure, a substantial number of people, about ninety, have been included in the TTOs.

The projects financed had as a common matrix the objective of increasing the intensity and quality of technology transfer processes from universities and public research bodies to enterprises through the reinforcement of the staff and the strengthening of the skills of the TTOs of Italian academia and public research bodies, in order to increase the innovative capacity of enterprises, particularly small and medium-sized ones, by facilitating the absorption and development of scientific and technological knowledge in specific production sectors and local contexts.

The activities carried out by the candidate within the project concerned the strengthening of the TTO to focus more on the protection and transfer of industrial property rights related to specific production sectors, supporting their valorisation activities. The development plan of the activities carried out by the candidate is divided into two sub-plans, each including specific activities, which are carried out in parallel.

The first sub-plan relates to the performance of activities focused on the protection and transfer of industrial property rights relating to specific production sectors. This sub-plan is aimed at carrying out activities ranging from technology scouting to the framing of project ideas from the point of view of the target market and possible application scenarios, evaluating from time to time the appropriate industrial property protection. The focus of this sub-plan is on academia research groups.

The second sub-plan, on the other hand, concerns support for the valorisation of industrial property rights, increasing opportunities for contact and promotion towards the business world, as well as activities and initiatives aimed at encouraging technology transfer of these rights. The focus of this sub-plan is on companies located in the territory.

All the above phases are part of a development process closely linked to the mapping and identification activities carried out in order to reach a point of arrival, marked by the success of products placed on the market.

The activities carried out by the candidate within the project financed by the Ministry concerning the strengthening of the TTO are presented in Figure 3.

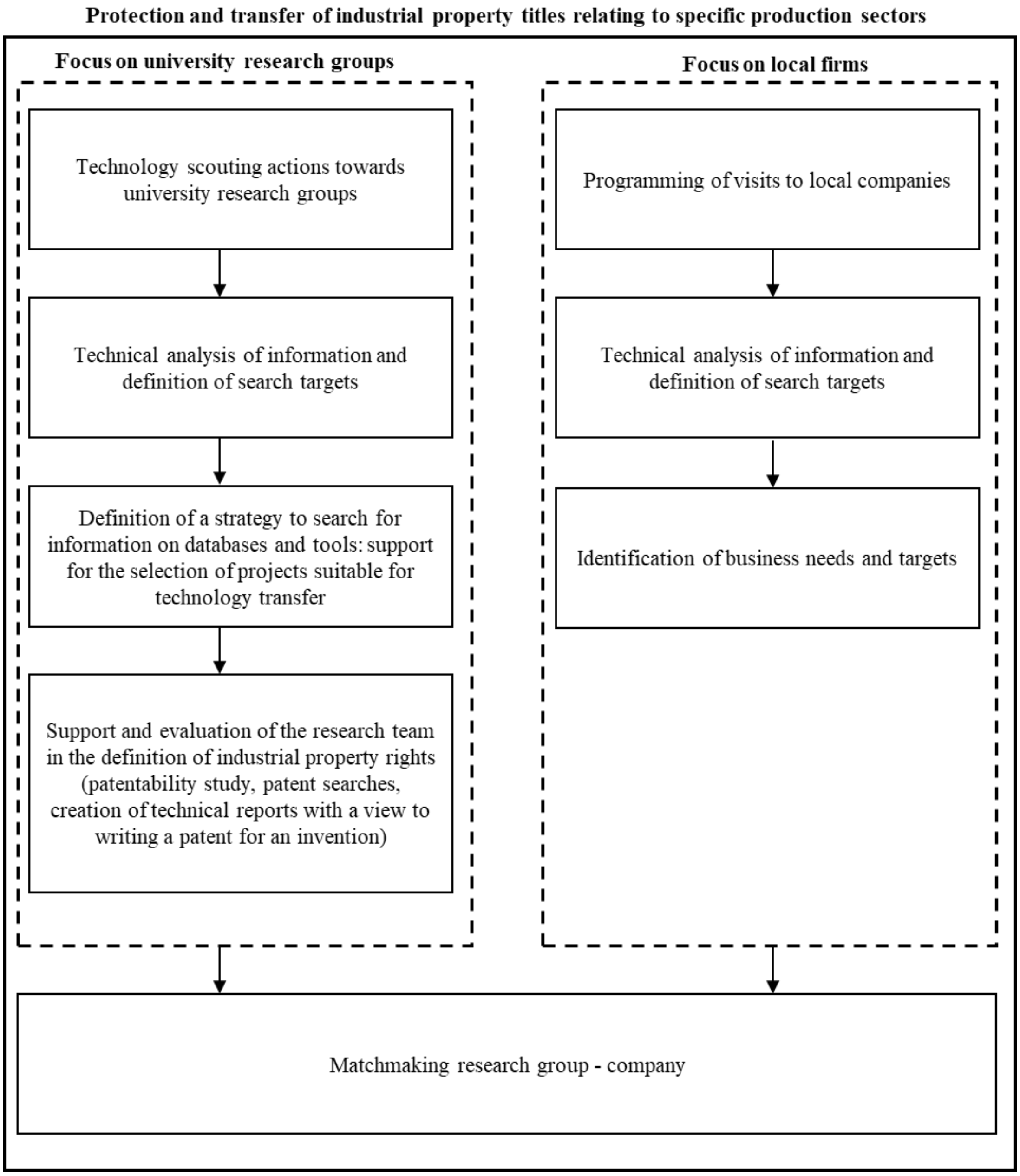


Figure 3. Description of the plan of activities concerning the protection and transfer of industrial property titles pursued by the candidate within the project of strengthening the TTO.

In addition, the candidate had the opportunity to operationally support the University for Innovation (U4I) Foundation initiative established by notarial deed dated 11-04-2017.

U4I, is an initiative at the service of innovation and technology transfer constituted by three academia: University of Bergamo, University of Milano-Bicocca and University of Pavia. The foundation was officially established in April 2017 with the aim of achieving an adequate exploitation of research results, facilitating the relationship between the laboratories and the market and encouraging the development of new products and services resulting from the synergy between the three universities.

The missions of the U4I Foundation can be summarised as follows:

- exploiting research and development results through projects with a high impact on people and society;
- gathering challenges and opportunities from stakeholders;
- create relationships with industrial partners and financiers;
- enhance the patent portfolio of the founding universities promoting the initiative.

The management of the activities is entrusted collegially to a board of directors chaired by Professor Remo Morzenti Pellegrini and composed of six members: three Rectors and three Vice-Chancellors (or delegated by the Rectors) each belonging to the three founding universities. As for the operational structure, it is composed of three pro-rectors, an interim director from the business world and support professionals with specific skills in technology transfer processes to manage the actions on which the Foundation's missions are based. The latter figures, which include the candidate, serve in the TTOs of the founding academia.

In order to promote the culture of innovation, encourage contamination between disciplines and build a bridge between academia and the business world, the Foundation proposes calls for ideas, called innovation project funds, with the aim of supporting the development of the ideas of researchers and research groups from the three academia, encouraging their technological maturity, bringing them closer to the market and bringing them to the attention of possible investors.

With these funding calls, the U4I Foundation intends to contribute to the fulfilment of the third mission of the founding promoting academia, in the field of the enhancement of research and technology transfer, by selecting research projects in progress in the three universities to which funding can be given to enable the transition from an idea to a product/process/service of industrial and/or social interest. The objective is to support the proposers in the implementation of a specific work plan lasting eighteen/twenty-four months that brings the results of the research activity to a level of industrial and social maturity, enhancing it (if this has not already been done) with the most appropriate form of legal protection and bringing it closer to the market through technology transfer actions such as licensing and/or the creation of spin-offs.

At the level of technological maturity, eligible proposals concern contributions, including interdisciplinary ones, at an early stage of research for which there is already evidence of the effectiveness of the proposed solution and which require support for further technological advancement and market success. In particular, reference is made to contributions that potentially result in the use by external parties of innovative scientific and/or social knowledge and skills (both in the technical and cultural fields) through the transfer of applied plans, projects or designs, relating to new and original products/processes/services.

Figure 4 outlines the operational functioning of the U4I Foundation in relation to the selection, funding, support and valorisation of project ideas arising from academia research.

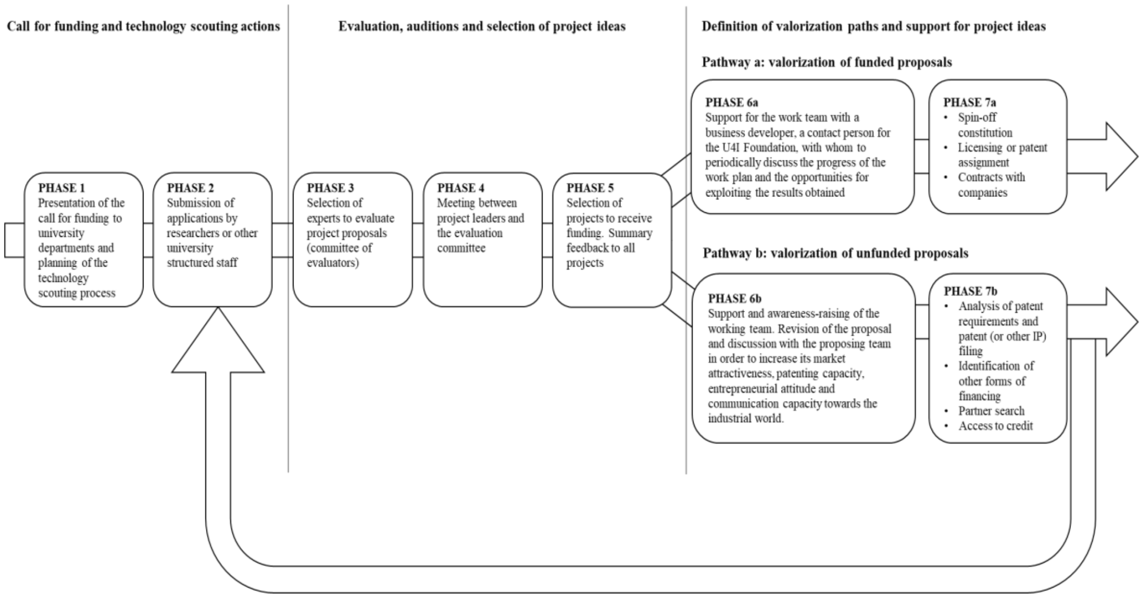


Figure 4. Selection, funding, support for selection of project ideas, carried out by the U4I Foundation.

In this context, the activities carried out by the candidate, as the operational contact person appointed by the University of Bergamo, concern technology scouting activities in order to identify project ideas born within the research groups belonging to the departments that have a relapse in terms of competitive development in a three-five-year horizon.

Afterwards, support for the drafting of the call for proposals and, finally, for both the ideas that are financed and those that are not considered suitable for financing, discussion with the representatives of the various projects on the progress of the work plan and the opportunities for exploiting the results obtained.

Technology scouting therefore starts with a preparatory analysis for the meeting with the research group aimed at investigating the state of the art, and continues with a meeting with the research group during which information will be collected and awareness and support actions regarding patent issues will be carried out. Once the meeting is over, there follow phases aimed at re-elaborating the information collected, defining a specific exploitation path for each project idea identified, coinciding with support for the drafting of the call for proposals that will be forwarded to the U4I Foundation to access the credit that brings the idea to proof of concept. Therefore: formulation, revision and drafting of project proposals.

2. State of the Art

2.1. How to support technology transfer

Technology transfer is a wide and heterogeneous collection of issues and activities. One of them concerns the collaboration between academia and industry to transfer the research results from the first to the second. This dialogue is sometimes difficult due to organizational issues, different objectives and communication problems due to the different level of technical and scientific preparation. Furthermore, a shared methodology to support technology transfer from academia to industry is still missing. In this sense, the biggest challenge is being able to bring together different figures in academia and industry, since technology transfer cannot be undertaken only through the insights of a particularly brilliant entrepreneur.

The main supporting approaches refer to Information retrieval, to deepen the results of research in relation to application fields and other contributions to the state of the art, and to Business evaluation, to understand whether the research results may have commercial opportunities.

The main supporting approaches for each of the two areas are presented below.

Finally, the main open problems relating to technology transfer and the application of supporting methods, collected from the literature and during the candidate's working activity at the TTO are presented.

2.1.1. Information retrieval

A key role in the valorisation of research results to foster technology transfer has been performed in recent years by their in-depth analysis, exploiting the information that can be gathered from the supporting literature. In this way, it is possible to understand the real similarities and differences of the research results in relation to what was previously proposed and to enhance them with information useful for technology transfer, such as the identification of application fields.

Several authors have extracted such information from patents (e.g. Altuntas and Dereli, 2012; Ji-wu and Lu-cheng, 2007). From these sources, several types of information were extracted in a systematic way, including trends and predictive statistics to understand the evolution of a technology (e.g. Li et al., 2007; Fall et al., 2003), or more technical information to improve product design, such as functions, behaviours, physical effects, processed objects, devices, materials, structures, forms, etc. (e.g. Kitamura et al., 2004).

To facilitate this work, automatic text analysis tools for processing natural language texts have been introduced, reducing execution times, analysing larger numbers of documents and reducing examiner subjectivity (e.g. Rush et al., 2007; Savioz e Blum, 2002; Wang and Li-Ying, 2014). These works can be classified in many ways depending on the search logic (e.g. by function or by structure), the degree of automation, the text analysis mechanisms (e.g. syntactic or semantic), the amount of analysed data and the types of extracted outputs.

These tools are used to transform free, unstructured text, from documents of different types (e.g. patents and papers) into structured and normalized data. Both academia and industry extensively tested the maturity of Natural language processing technique, highlighting its reliability in precisely understanding a description, to the point of being preferred to econometric methods for the economic evaluation of a patent (Hasan et al., 2009).

In turn, Text mining techniques can be divided into four sub-categories.

- Purely syntactic patterns (e.g. Cimiano et al., 2006) simply perform the syntactic analysis of a sentence, by assigning a syntactic role to the contained words, i.e., subject, verb, direct object, other indirect complements. Since the classification of extractable information is only syntactic, the involvement of an expert is necessary to interpret and classify them in a technical way. While, to obtain information more relevant, some methods (e.g. Spreafico et al., 2019) analysed documents collected through a search query involving, for instance the terms "circular economy" and related, e.g. "recycle" and the name of the waste.
- Entity-based recognition approaches embedded with syntactic parsers associate user-defined ontological roles with the elements of the sentence. Among them, some approaches, referring to the Technical System Object Product model ontology or models based on similar classification, can be a starting point for the study conducted in this dissertation, even if the link with the circular economy is not explicit. Some of them (e.g. Litvin, 2005; Cheong et al., 2015) discriminate

the technical Functions performed, including the transformations used to recycle a waste, among all verbs, including state verbs, e.g. “be, consist of, comprise”. Other studies (e.g. Cascini et al., 2004; Yoon et al., 2015) identify the Object, i.e. the entity that undergoes the Function and the Technical system performing the Function. In this way, when the Object coincides with the treated waste, the technologies that can be used to transform and recycle the waste can also be identified, although this is not the purpose of these methods. The Technology tree ontological model of Choi et al. (2012) is an alternative to the Technical System Object Product model, allowing to connect multiple Technical systems performing different Functions on different Objects. In some cases, (e.g. Moehrle et al., 2005; Russo et al., 2020) dependency patterns are introduced to improve the effectiveness and correctness of the syntactic analysis of a sentence. The latter are recurring forms, including prepositions and constructs, linking together the different syntactic parts of the sentence, e.g. "Subject + to, for, can, as, by, of, used to, used for, should, to obtain + verb".

- Topic modelling, in addition to associating ontological roles to sentence elements, as in Entity-based recognition, it also recognises the syntactic roles of elements. The similarity link used to recognise ontological roles can involve several criteria such as the precise equality of the terms or of the root, synonymy, kinship (e.g. the term "credit card" is recognized from the topic "bank"). Usually, with this method, an expert able to collect the most strategic topics also has more chances to obtain more relevant results. To bypass this obstacle, some authors suggested ready-made and reusable topics lists for certain arguments, including the circular economy. For instance, Mahanty et al, (2019), analysing scientific papers, identified topics enabling the identification of methods for waste management, recycling, and product redesign for easier end-of-life reuse. Another advantageous during patents analysis is to collect the topics from patents classes descriptions. For instance, to evaluate the technological similarity between patents, Arts et al., (2021) search in their texts for the presence the common terms from the classes descriptions provided by the United States Patent Classification System. These studies showed that patents are more similar from a technological point of view when belonging to the same patent family.

- Named entity recognition employs a similar operating principle of topic modelling, with the advantage that topics are automatically extracted from industry-ready libraries, such as SpaCy named entity visualizer or OpenNLP (e.g. Van Capelleveen et al., 2021). While the works of Zhai et al., (2019) and Akhondi et al., (2019), albeit not specifically related to circular economy, allow for the identification of the products of chemical reactions of certain reagents, including wastes. While Van Capelleveen et al, (2021) identifies and classifies the wastes based on the contained materials to plan the subsequent recycling or reuse operations.

As part of technology transfer, these approaches are used for the automatic analysis of text both because they allow the extraction of information relevant to the design process, which is difficult to identify due to unstructured documents (Chiarello et al., 2017), and because they allow to exploit publicly available sources, helping in resolving the problem of non-availability of data used in engineering design research, for instance open sources software repositories or open business registries (Parraguez and Maier, 2017).

The Text mining techniques for engineering design extraction of entities, can be classified according to the problems that they are helping to face concerning the context of knowledge management (Chiarello et al., 2019). They are therefore distinguished in knowledge extraction methods for the automatic identification of design knowledge form (mainly product features identification) and unstructured document sources: surveys, interview transcript with expert in the fields and consumer opinion data (Jin et al., 2016). The objective of these methods concerns the analysis of data, from the viewpoint of product designers, and how these results will benefit designers for market-driven product design. Typically, analyses of this kind are based on about 100,000 reviews.

The results obtained from these methods should be discussed with experts who read topic models output and go further and make sense of the results. Then, the results must be evaluated with indexes for the analysis of the similarities of the topics extracted. However, the adoption of semi-automatic search mechanisms makes it possible to overcome some of the problems that are used to be encountered with direct expert confrontation, mainly summarised in the fact that experts rarely apply systematic rules, and their opinion may be subject to some biases, such as, for instance, the desirability bias that comes when expert attributes a higher probability of occurrence to preferred events (Noh et al., 2015). Fantoni et al., (2021) proposed a method for the semi-automatic extraction of technical and design information from a dataset of documents (corpus text of about 1 million words) whose contents is both legal and technical. The objective of the research is to organize the identified information (e.g. product structures) with the aim of transforming customer's requirement into design specifications. A manual validation with experts in the fields regarding the information extracted shows a validity of about 90% of the results achieved.

Recent developments in the patent analysis literature have made available software systems that are able to automatically extract information from patent documents, transforming raw texts into structured data. Researchers in this field follow two main approaches: keyword approach methods that can produce vector representations of the analysed documents and grammatical and syntactical approach. The last methods are based on grammatical and syntactical structures provided by Natural language processing tools, such as Part-of-Speech (POS) taggers and syntactical parsers. Unlike the keyword approach, these methods can capture the relationships between the entities mentioned in the same sentences (Yoon et al., 2015). Regarding the second categories of approaches based on Natural language processing tools, an interesting branch of research deals with the combination of the syntactic parsing tools with patent ontologies (Ferraro and Wanner, 2011). Patent ontologies are fundamental concepts and relations inside a patent text. They can be classified, for instance, in structural information of the document, e.g. claim section, description, basic information, e.g. patent number, inventor, title, and technical features, e.g. application fields, working principles, materials (Wang et al., 2015).

In the following, the three main activities to be undertaken during the Information retrieval phase, e.g. (1) Selecting the supporting methods and tools, (2) Collecting the documentary sources and (3) Selecting the search strategies, are explained in detail.

Selecting the supporting methods and tools

Syntactic parsing methodology analyse an input text build a hierarchical syntactic structure according to the role of each word inside a phrase. For instance, subject – action – object (SAO triads). This method is employed to simplify complex phrases in small and more readable utterances (Wang et al., 2015). At present, SAO triad approaches do not cover all kinds of technical features. For this matter, with the aim to enlarge the coverage of technical features to be identified, it is necessary to define specific search strategies for identifying each feature (Kim et al., 2014). The parsing procedure applied in this regard for the extraction of useful information from a patent text starts with the computation of the relations among the words that compose a sentence (called tokens) and encode a dependency graph of the structure identified. In this regard, the dependency identified are the so-called binary-syntactic relationships (e.g. nsubj, pobj, prep, det) (Srinivasa-Desikan, 2018). These dependencies are limited in number and changes according to the software adopted for the analysis. With the objective of identify a feature inside a patent syntactic parser is only a part of the method and the approach requires linguistic patterns.

The automatic analysis of technical documentation implies two categories of challenges. The first type is the one common to the processing of all documents written in natural language. Natural Language is subject to polysemy (the property that a word must express multiple meanings) and synonymy (relationship between two lexemes with the same meaning). The second one is related to technical domain (terms, relationships, standards, etc.).

The literature regarding the automatic analysis of texts technical features through Natural language processing includes different approaches: from expert systems that adopts human knowledge implies to solve data problems by emulating the work of the experts (Munaiseche et al., 2018) to machine learning approaches based on AI tools that develops algorithms able to automatically learn from data and identify hidden patterns (Al-Sahaf et al., 2019). According to Oliva (Oliva et al., 2021), documentary source texts can be classified in different kinds: structured, unstructured, and semi structured. For what concern unstructured data, the automatic extraction of useful information from a corpus text are provided by Natural language processing tools known in literature also as text mining and information extraction (Jurafsky and Martin, 2000).

Natural language processing algorithms aim to analyse text, extract information, and represent it in a different manner. For instance, a text can be transformed to some other structure preserving the main part of the content (e.g. summarization), or be broken in parts so that categories can be associated (e.g. part of speech tagging, sentiment analysis), or be structured in another format (e.g. parsing) (Conneau et al., 2016; Collobert et al., 2018). According to Fantoni et al., (2021) the main criticality of Natural language processing tools for the identification of information from a text relies from POS tagging: the process of assigning grammatical categories to words in context. Although the high percentage of accuracy, a POS tagging error may affect all the following steps that compose the Natural language processing analysis.

In this regard, several systems for information extraction are constrained to extracting binary relations that are declared within a single sentence (intra-sentence analysis). As consequence, this aspect limits the proportion of relations they can extract since those expressed across multiple sentences (i.e. inter-sentential relations) are not considered. The analysis of Swampillai and Stevenson (2010) showed that 28.5% of the relations in a text occur between entities in different sentences. Inter-sentence relations for the extraction of information from a text deals with some complex semantic relationships in documents, which require syntactic and semantic dependencies. Existing methods do not fully exploit such dependencies (Sahu, 2019). With the aim to extract inter-sentence relations, most approaches adopt distant supervision to automatically generate document level corpora and dependency trees for the extraction of syntactic relations between words (Shen et al., 2018). According to Mandya et al., (2019), an open issue regarding the investigation of inter-sentence relation extraction is the absence of a significantly large dataset with inter-sentence relation mentions. Previous studies on inter-sentence relation extraction have employed very small and field-specific datasets.

Mixed methods approach (e.g. kernel approach, Natural language processing with POS tagging) integrating intra-sentence and inter-sentence analyses can be effectively adapted to each other. However, the number of results obtained does not differ much from what can be obtained by means of intra-sentential relation extraction (Shen et al., 2018; Sahu, 2019).

To this aim, patent databases are valuable resources for the identification of technical systems or other design elements. Patents are acknowledged as a valuable source of information for several innovation-related purposes. An interesting approach uses the Cooperative Patent Classification as stimulus for guiding design and it is based on information retrieved from patent classifications used as trigger to generate ideas for new product applications. The elements are extracted only if the relations Subject (S), Action (A) and Object (O) are in the same sentence (Fiorineschi et al., 2019).

In the field of technical documentation analysis, a few ontologies have been successfully proposed in a variety of research projects, mostly focusing on upper-level concepts hand-crafted by domain experts. Large knowledge-based applications in the specific domain will need more and more comprehensive ontologies that should be moreover continuously updated (Cavallucci et al., 2010; Chiarello et al., 2018). To avoid this problem, various techniques for automatically acquiring knowledge from text using information extraction methods have been proposed in the Natural language processing research community in accordance with systems that automatically induce ontological knowledge from texts with an ontology learning system (Fantoni et al., 2013). The system offers a battery of tools for Natural language processing, statistical text analysis and machine language learning, which are dynamically integrated to provide an accurate representation of the content of vast repositories of unstructured documents in technical domains. Limits regards the identification of features with certain paragraph including numbers of single requirements. These are difficult to fit and to be exploited. Russo et al., (2020), instead, proposes an approach based on patent data sources for the extraction of a list of entities that occurs in the same sentence. The methodology employs function-based approach embedded with syntactic parsers and other Natural language processing applications. The system becomes more complex the longer are the cause-effect chains between entities. From a sample of 1000 documents, the features extracted by a SAO approach equates to 37% of the features extracted with other dependency patterns.

Collecting the documentary sources

To get an idea of the technologies and products on which international research is most active, one of the richest sources is undoubtedly the archive of scientific publications. Among these the authors have chosen Scopus database. The Elsevier Scopus database offers access to STM journal articles and the references included in each of those articles, allowing the searcher to search both forward and backward in time. The use of the database is for both collection development and for research. According to the website, the database contains over 22000 titles from more than 5000 international publishers.

One of the most suitable tools for the identification of documentary sources necessary for the extraction of technological features is contained in patent databases. They are divided into public, e.g. Espacenet, and private databases, e.g. Orbit Intelligence patent database. With Espacenet, users can freely access the data contained in more than 130 million patents worldwide while with Orbit Intelligence database is possible to work with a comparable number of worldwide patent collection but grouped by invention-based families containing bibliographic information, full-text, and legal status other than graphical representations and other functionalities.

There are also interesting works (e.g. Lee and Lee, 2017; Castaldi, 2020) that uses both patent data and trademark with the aim to investigate a firm's gods and services, or scientific papers (Xu et al., 2019).

Market analysis is a specific analytical research that companies use to study the economic context in which they operate, the reference sector of their activity and the behaviour of their target audience. A correctly carried out market analysis allows commercial realities to become aware of profit opportunities or risk factors present in a given market.

A tool used to find information of an economic nature about companies and markets is the Orbis database from Bureau Van Dijck that offers analysis related to comparable data on companies around the world, mark-up projections, brand-equity, aggregate volumes, and characteristics of the various levels of the value chain.

The database collects business records from individual companies and it collects the most relevant firm's database in each country considering quality, insurance, category of firms, and accuracy of the information. The Orbis database organizes these public data from administrative sources and filters them into various standard formats to facilitate searching and company comparisons (Flignor and Orozco, 2006).

Selecting the search strategies

There are numerous examples in literature concerning technology trasfer, most of them have in common the exploitation of the same source of information, for instance the patent database (e.g. Altuntas and Dereli, 2012; Ji-wu and Lu-cheng, 2007). TRIZ methodology (Altshuller, 1984) exploited function-based research to find the solutions for an initial problem by gathering them from the literature about nearby fields The first practical implementation took place in 1988, and then spread to the rest of the world under the name of FOS- Function Oriented search (Litvin, 2005).

Already in the 1990s, the first software implementations were born, such as the Goldfire Innovator (patent WO2010/105214), one of the first software applications capable of processing the patent text (in English) using a syntactic parser trained to extract SAO triads. Thanks to this tool, the user could extract a list of documents containing a predefined A-O pair and search within them with the aim to identify, within the subjects found, if there were alternative products (or technologies) to the original one. Similarly, it was possible to navigate among the documents that shared the S-A pair and then classify the O objects by field of application. From the FOS, many other methodologies have emerged within the TRIZ community, such as ZIRT (Souchkov, 2007), Litvin's works (Litvin, 2005) but also outside TRIZ (Choi et al., 2013).

More recently, tools for analysing intellectual property data have become more and more widespread, also including artificial intelligence methods, machine learning and deep learning approaches, used for many different applications such as knowledge management, technology management, economic value, and extraction and effective management of information (Aristodemou and Tietze, 2019). There were also contaminations with other methods, such as functional analysis (Cascini et al., 2007), or contamination with FBS techniques (function-behaviour-structure) (Fantoni et al., 2013). An old idea introduced by Hearst, by using domain-independent extraction patterns to generate candidate facts, (Hearst, 1992) and implemented more recently by many others (Etzioni et al., 2004).

However, there is no lack of examples of the use of Natural language processing instruments even in combination with more traditional, non SAO-based techniques, exploring patent classes with statistical approaches (Fiorineschi et al., 2018) or in Technology Opportunity Discovery (e.g. Park et al., 2013; Lee et al., 2017). The last few years have seen a surge in the number of accurate, fast, publicly available dependency parsers. At the same time, the use of dependency parsing in NLP applications has increased, reaching results and precision which seemed to be unattainable until recently (Choi 2015). A further approach is to exploit sophisticated Artificial Intelligence methods, preferring algorithmic methods based on language rules, generic patterns or domain-specific patterns to extract technological features.

Finally, there are integrated approaches (Chiarello et al., 2017), which use patents for automatic requirements extraction using keywords related to specific concepts (for instance benefits, gain for desired requirements) associated with NLP tool and syntactical parser.

In 2014, Murphy created a complete functional vocabulary extracted from the target knowledge based on the United States Patent Trademark Office patent database (USPTO), in order to classify patents for supporting design by analogy (Murphy et al., 2014). More recently (Sarica et al., 2019), construct TechNet, training the word embedding models (as word2vec or GloVe algorithms) on the complete United States Patent and Trademark Office database patent text database in order to construct a comprehensive semantic network of engineering concepts with technically-meaningful semantic associations. In 2019, Luo by utilizing the complete United States Patent and Trademark Office database patent text dataset proposes a network map of all technology domains based on the international patent classification which are connected according to knowledge distance based on patent data (Luo et al., 2019).

Open problems from the literature concerning Information retrieval

Although the presented supporting methods and tools have brought several advantages for technology transfer, several open problems have been detected in the literature. In the continuation of this section, a selection of the most common ones is reported.

Technology transfer field is very wide and heterogeneous and it requires collaborations between engineering, economic and computer science approaches.

- Several supporting methods are not facilitating this collaboration, being rather mono-thematic in the jargon used and in the proposed usage modalities (e.g. Wang et al., 2015; Shinmori et al., 2003).
- Many Information retrieval methods still leave too much space for manual knowledge acquisition and analysis, with the resulting limitations in terms of time, cost and accuracy of results (Russo et al., 2020).

- Many times, specific knowledge of the field of analysis is required to build the document pool, provide strategic input during automatic text analysis, and classify the results obtained. Thus, the contribution of the expert is still crucial (Bukowski et al., 2020).
- The user does not always have control over all the phases of the analysis and the possibility to customize the research according to his/her specific needs when this task is demanded to the developer (e.g. Bukowski et al., 2020; Russo et al., 2020).
- Natural language processing tools uses parser method trained to work on non-technical English texts while the patent text is a mix of jargon, technical, legal language and machine translation (e.g. Chiarello et al., 2018; Wang et al., 2015).
- Different semantic dependency parsers have different accuracy in recognizing relationships between words in a sentence. The error propagation depends on the selected language, the complexity of the sentence, its length and the type of technology used by the parser (Kurtz et al., 2019).
- In many methods proposed for implementing FOS approach, the role and capabilities of the user have a great influence on the result, especially for those that use the method more freely as an inventive trigger (e.g. Aristodemou and Tietze, 2018; Litvin 2005).

2.1.2. Business evaluation

Developing a technology transfer methodology requires not only the identification of potential new fields of application, but also a method to measure the potential replacement of the new technology compared to those already on the market, comparing the different results obtained in the research phase and suggesting the best investment to make. This choice depends on many factors including: the maturity of the product, the structure of the reference market, the identification of areas still free from marketing and/or patenting, the identification of the requirements on which to make the comparison.

To assess the maturity of the product there are several studies that describe the evolution of technical systems according to logistic curves or S curves (Park et al., 2013; Boretos, 2007; Kucharavy and De Guio, 2007; Bengisu and Nekhili, 2006). Among the different evolutionary models, (most of them based on purely qualitative reconstruction), a quantitative approach based on the combination of four analyses is noteworthy: the evolution of the performance of the main function of the product, the inventive level in terms of how much and how a contradiction is overcome, the number of inventions and the profits associated with the single product (Savransky, 2000).

Although there are no scientific studies that have demonstrated the reliability of this approach, the dissemination of these studies has made it possible to investigate when and how a mature product gives way to a new product, the new S curve. This principle is extremely interesting for the purposes of the technology transfer research, since the new system most often coincides with a product that exploits the technology to promote, for instance the target of the research.

In Figure 5, a representation of general S-curve characteristics is provided.

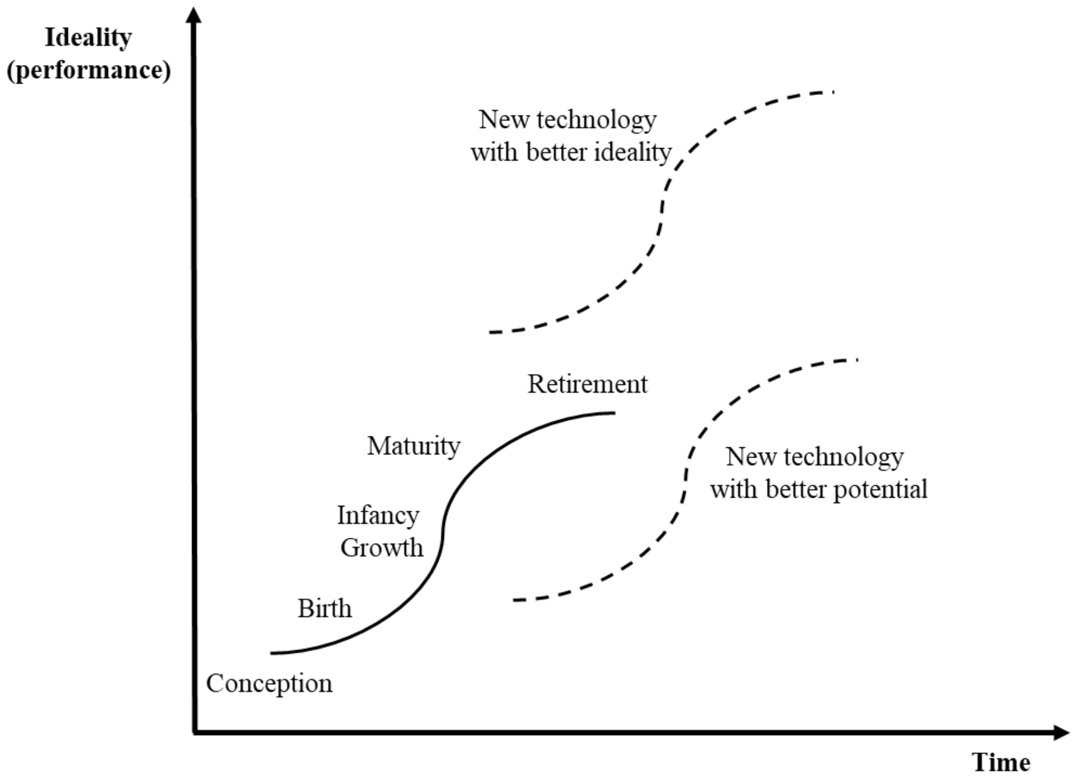


Figure 5: Evolution of the technological system through the concatenation of S-curves and representation of general S-curve characteristics.

Evolutionary studies help to understand what parameters need to be considered when evaluating the maturity of a product, and how strategic it can be to look for this information in the patent source. The question of how to manage the evaluation of a multicriteria analysis remains open.

Among the various approaches used to evaluate the market potential, a technique consists in the evaluation of a series of customer needs and requirements. These approaches are able to define customer needs or requirements, with a structured procedure to trans-late them into technical parameters and plans to produce products that essentially meet those needs.

Benchmarking is one of the first form of structured product development. Products are compared with industry bests from other companies and improvements are planned to cover possible gaps or to overcome competitor’s performances. In particular, satisfaction is a measure of how products and services supplied by a company meet or surpass customer expectation. In a scale from 0% to 100%, 0% is the absence of the feature or great dissatisfaction, 100% is maximum satisfaction. The aforementioned definitions are given to experts before the interviews for the evaluation.

In this regard, the market potential method consists of a dual analysis: satisfaction and importance of requirements from a customer perspective. Importance (I) is the degree of a requirement to influence the customer decision. Importance also considers company investments made to improve requirements (Jacoby, 1977). A 0-100% scale is used, where 0% is no important and 100% is absolutely important. Satisfaction (S) measures the capability of a technology to fill or overcome customer expectations for a specific requirement (Farris et al. 2010). Differently from the importance that only depends on the application thus it is a unique parameter for all technologies, satisfaction is assessed for each technology.

According to Ulwick (2002), for a certain requirement i, the market potential of a specific technology can be calculated as:

$$Market\ Potential_i = 10 \cdot \left(1 + \frac{I_i}{100} + \left(\frac{I_i}{100} - \frac{S_i}{100}\right)\right) \tag{1}$$

Where, $Market\ Potential_i$ is the market potential of the requirement i for the technology considered, I_i is the importance of the requirement i and S_i is the satisfaction of the requirement i. According to this formula, requirements with high importance and low satisfaction generate high market potential.

The assessment of importance and satisfaction is carried out through interviews and audits with marketing and sales experts.

The value of all market potentials is plotted in an xy graph where the x-axis is the percentage value of importance and the y-axis the percentage value of satisfaction. The requirements which present the highest values of market potential and, consequently, present the values for which it is most convenient to carry out the technology transfer as the market potential technique confirms innovation are arranged in the bottom right-hand corner.

An example of a graphical representation of the market potential matrix is shown below in Figure 6.

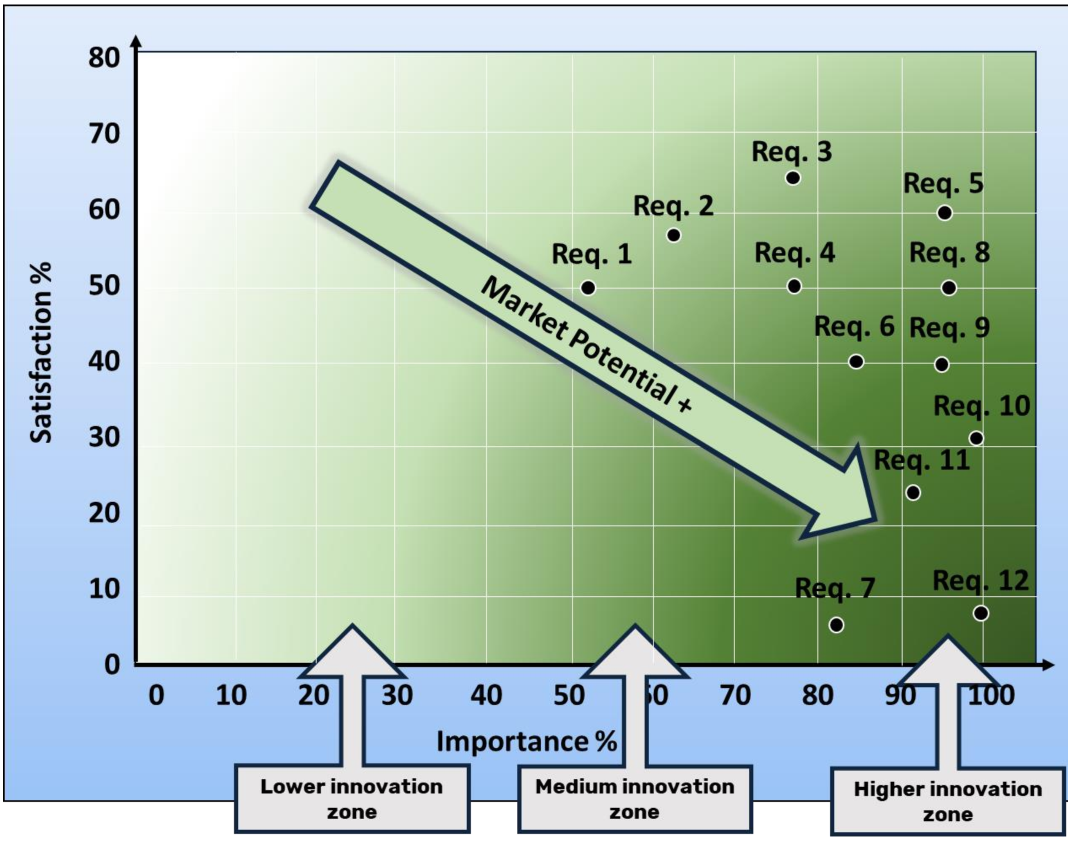


Figure 6: Example of market potential graphical analysis.

Indicators for Business evaluation

Concerning innovation indicators, a distinction must be made between what are considered innovative input indicators and what are called innovative output indicators. With input indicators is generally mean to define that category whose objective is to measure the available resources, especially when talking about performance indicators. In the case of innovative inputs, these indicators measure the resources available to the innovative activity.

While, with output indicators, on the other hand, it is usual to define that type of parameter whose aim is to measure the results of the activity and are particularly useful for making references with other organizations. In the case of innovations, on the other hand, output indicators measure the actual innovative performance (Lee et al., 2009).

The main problem, with reference to the measurement of innovative activity, is precisely to identify appropriate measures as indicators of innovative input and output, thus becoming necessary to decide the level of analysis; if one wanted to measure the innovative activity of individuals, a good indicator would be the scientific productivity of the various researchers (scientific publications), while if one wanted to measure the innovative activity of projects and organizations, it would be necessary to focus attention on companies, universities, and research centres.

However, those enabling factors that are essential for the development of new technological solutions, such as the availability of adequate financial resources especially for its early stages, which are characterised by a high level of uncertainty with respect to its outcomes: these resources are often provided by venture capital, specialised companies that act as intermediaries between the financial system and young companies: venture capital represents one of the most important sources of capital for companies with significant innovation objectives.

Valuation techniques used by financial intermediaries include those based on qualitative or quantitative assessment of the value of patents (Clarke et al., 2020; Dernis et al., 2004).

As stated by Lagrost et al. (2010), the approaches for evaluate patent costs are divided in two categories: the quantitative and qualitative valuation. Quantitative approach relies on numerical and measurable data with the purpose to calculate the economic value of the intellectual property, while the qualitative ones are focused on the analysis of the characteristics and potential uses of the intellectual property. Qualitative valuation deals also with assessing the risks and opportunities associated to the intellectual property of the company.

The methods most often used to obtain an estimate of the economic value of a patent may be reduced to three types (Flignor and Orozco, 2006). In Cost-based methods, the identification of the value of the patent as the sum of the costs that have been incurred to obtain it. Methods-based on market data are aimed at determining the value of the patent by comparison with other similar patents, the market value is known, e.g. the awareness of the price at which the patent was sold.

Finally, methods based on future economic benefits, determine the value of the patent as the present value of the economic profits that the patent provides to the owner over the residual useful life of the patent.

However, intangibility does not refer to the intangibility of intellectual capital, but rather to the fact that it is not easily translatable into financial terms. All other assets of a firm, such as a building or debt securities, can be monetized, in the sense that there are standard criteria for expressing their value in terms of current currency (Neugebauer et al., 2016).

Intellectual property, on the other hand, is mainly constituted of elements (such as the quality of personnel or the reputation of the brand among consumers) for which there are no universally accepted methods for their valuation. However, there are many methods for carrying out a quantitative valuation of patents and they are often used at different times depending on the reason for the valuation.

If before these methods were used in a very quick and approximate way in the case of company spin-offs, mergers or acquisitions, now they have become more important since, following the adoption of the new international accounting standards, it is possible to include intangibles in the balance sheet and also and above all since intangibles have become the core of the business of many companies. There are several purposes for which a valuation is carried out: balance sheet entry, patent transaction, licensing, mergers or spin-offs of companies, quantification of damages during lawsuits, valuation of assets of a failed company (Moore, 2017; Neugebauer et al., 2016).

Open problems from the literature concerning Business evaluation

Although the presented supporting methods and tools have brought several advantages for technology transfer, several open problems have been detected in the literature. In the continuation of this section, a selection of the most common ones is reported.

Technology transfer field is very wide and heterogeneous and it requires collaborations between engineering, economic and computer science approaches.

- Some methods tend to leave too much space to the knowledge and personal intuition of an expert or the entrepreneur, leading as a consequence to overly subjective and sometimes questionable results (Battistella et al., 2016).
- The methodologies for the comparison of technologies directly depends on the number of alternative technologies already active on the market, affecting the complexity and time of the entire decision-making process (e.g. Farris et al., 2010).
- The use of patents as indicators also has its limits: there is not always a correspondence between innovation and patented inventions, just as not all patented inventions have a technical value (Russo et al., 2020).

3. University of Bergamo TTO organizational structure

The candidate, during his PhD studies, worked at the TTO of the University of Bergamo, a job that allowed him to fully learn the organisational structure of the Office, the subdivision of activities offered by the academia ecosystem, the academia-business collaboration and the way the office staff operates on a daily basis.

In this context, as presented in Section 1, the candidate has also had the opportunity to collaborate with external partners and entities, dealing directly with research exploitation activities, understood as the set of activities through which the original knowledge produced by academia through scientific research is actively transformed into productive knowledge, susceptible to economic and commercial applications.

Within the TTO, the candidate has worked as a Knowledge Transfer Manager in a liaison role between the world of academic research and the world of industry in order to exploit research findings towards companies potentially interested in developing and commercialising innovations.

Within this technology transfer path, characterised by a starting point (research), a series of intermediate stages and a finishing point (the market), intellectual property is of fundamental importance, which can be almost entirely encapsulated in the patent, at least for the academia context in which the candidate worked. In this regard, the activities directly followed by the candidate concerned and still concern the management, protection and exploitation of intellectual property.

In addition to providing a sort of guarantee for all those who create innovation within the world of research, intellectual property essentially plays a linking role with the world of production and business. In this perspective, intellectual property makes technology transfer safer and more efficient, thus facilitating the exploitation of innovation by existing or new companies (spin-offs and start-ups). Support for patenting, however, is not an end in itself, but must be trained and included in an appropriate methodology that allows to understand the novelty, the function performed by the invention and suggest to the researcher or the company paths of exploitation and technology transfer. It is within this sphere of activities that both the work and the research of the candidate were focused on.

The collaboration with the TTO enabled the identification and extrapolation of a number of open problems related to knowledge acquisition for technology transfer. These problems were essential and the starting point for the formulation of the scientific methodology.

This Section describes the activities that led to the identification and subsequent classification of open problems.

The established practice of the technology transfer office regarding support actions, in relation to the strand of activities addressed by the candidate and relevant to the exploitation of research, is usually limited purely to the administrative sphere.

The academia's support actions were mainly reactive in nature. Following a patent and/or spin-off application by a researcher, the Office limited itself to carrying out activities of an administrative nature.

Technology transfer, for internal academia policy reasons that are beyond the scope of this doctoral thesis, was treated in the same way as training and research, the so-called first two academia missions, which by their very nature have always been carried out by researchers and professors.

The innovation profession, on the other hand, requires strong cooperation between the research staff (without whom knowledge and technology cannot be generated) and the specialised staff of the technical-administrative structure (Conti et al., 2011).

But while classrooms and laboratories are sufficient for training and research, technology transfer requires methods and tools for its implementation: intangible infrastructures of different types and dedicated, such as knowledge management systems, specialised databases, specific programmes. It therefore requires, above all, those complementary and competing skills without which it becomes practically impossible to manage the process that leads from the generation of knowledge to its use on the market, through a series of complex activities.

The activities carried out by the candidate were therefore part of the five-stage model, presented in the introductory chapter (see Section 1), in which he had the freedom and autonomy to apply, for some of the stages that constitute the model, methods and tools that were only initially the result of a careful study of the state of the art relating to all the main bibliographic contributions that currently support technology transfer (i. e. systematic innovation methods and technology forecasting), search engine information (i.e. Google search) and technical database mechanisms for patent searches (i.e. systematic innovation methods and technology forecasting), information search from search engines (i.e. Google search) and functioning mechanisms of technical databases for patent searches (i.e. Espacenet, Orbit Patent Intelligence, Scopus, AskNature). These activities, together with the tools adopted, compose a framework serving the TTO.

This research has been made possible thanks to the willingness and flexibility of the TTO and the pro-rector delegated to technology transfer who, in accordance with the provisions of the University of Bergamo third mission strategic plan, have been working since 2015 to enhance the innovative and creative potential of the various disciplines - humanities, sociology, law, economics, business and engineering - with the idea of linking the concept of technology transfer to a broader and more integrated vision of knowledge transfer.

As a result, they enabled the candidate to operate the PhD study within his working activity as a research fellow with the qualification of knowledge transfer manager, developing a technology transfer methodology based mainly on documentary sources such as patents and scientific articles.

In this way, the TTO is enriched with a scientific method that supports both those who work in the office by extracting in a complete, precise and rapid way useful information for the daily activities carried out, as well as supporting the understanding of the technical proposals presented by teachers who need help in the valorisation of project ideas by making sure that the person conducting the interview can have a clear picture of the invention or project idea proposed in functional terms, that is, he/she can understand what is the main function that the idea wants to achieve.

This awareness is intended to be guaranteed, at least to a basic extent, regardless of both the interviewer's level of technical competence in the area of the idea and the presentation medium used.

The activities the candidate was involved in are described below, emphasising how the activities were carried out, what methods and tools were used.

3.1. Used procedure

During these collaborations, the candidate had the opportunity to deal with several case studies, many of which highlighted different aspects that, in the traditional TTO practice/method, can be defined as problems and lacunae.

Before proceeding to the description of the case studies it is appropriate to define, just in order to better identify the activities and processes of the functional model, which research agreements can be negotiated with companies. According to this terminology, it is possible to classify the type of case studies from a TTO perspective.

- Research contracts: consist of agreements that provide the framework for collaboration between the funding company and the academia. The contractual instrument of the agreement generically outlines the direction of the research programme; the agreement is then followed by implementation contracts that specifically define the terms of the research provision.
- Cooperative research: this is an agreement made when the enterprise expresses the will to preside over some specific knowledge. The framework agreement regulates the forms of sharing of personnel, facilities and laboratories of both the enterprise and the academy with which the collaboration is developed. Co-operative research is generally supported by national, EU and generally long-term funding.
- Development contracts: again, these are research agreements commissioned by companies, but they are separated from those already described because they involve the development of an already protected technology. The negotiation of these contracts usually develops from the intellectual property exploitation process when the company is interested in the technology but requires further development before entering into a licensing agreement. In this case, the company may proceed to finance the necessary research by securing the subsequent possibility of licensing through a time-based and conditional option agreement.

In detail, seventeen real case studies were addressed, which were used to identify eighteen classes of open problems:

1. Sol-gel composition for water-repellent finishing of environmentally friendly fabrics, obtained by application of an organic-inorganic ceramic coating with water-repellent, fluorine-free and formaldehyde-free properties.
2. Photocatalytic ceramic foams for the removal of micro pollutants. Development of a prototype to demonstrate in the laboratory the feasibility of a process for the degradation of organic compounds, involving the use of a catalyst and a support consisting of a synthetic mullite ceramic foam.
3. Redundant work piece table for machine tools and 3D printers. Definition of the layout of a machine tool and its control by introducing an additional degree of freedom into the machine architecture.
4. Microscopic analysis of fluid-porous surface interaction. Detailed processing of the results of X-ray micro tomography (micro CT), which is used to analyse the interaction phenomena between fluids and porous material surfaces at the microscopic level and to reconstruct very high-resolution (up to one micron) digitised objects in 3D.
5. System of dissipation and/or increased stiffness with displacement amplification. Activity to exploit a patented invention with technological maturity equal to TRL three concerning the most efficient way of using dissipaters, whether seismic or not, of various kinds (hysteretic, viscous, viscoelastic, magneto-rheological dissipaters...) capable of amplifying the relative motion caused by an earthquake, or other phenomenon, between two elements of the structure.
6. Tubular connector for the connection of mixed wood-concrete beams. Identification of a field of application of a patented invention proposing the development of a tubular connector capable of making a connection between solid structural elements by means of a tubular trace cavity without the use of resins and other adhesives.
7. Development of new shielding materials for buildings. Evaluation of the requirements leading to the writing of a patent for an invention, concerning the direct use of composite materials for construction, with shielding properties, thin and stratifiable (e.g. cement mortar and plasterboard), able to effectively replace metal cages without decreasing the shielding level towards electromagnetic fields.

8. Motion capture and data analysis systems. In identifying potential exploitation actions of an applied research activity concerning the automatic analysis of patients' movements in the medical field based on a data collection process (by means of marker-less motion capture systems based on RGB or RGB-D sensors), useful for doctors to formulate diagnosis/rehabilitation paths.
9. IoT edge-cloud platform for capillary and continuous monitoring of atmospheric air quality using low-cost portable sensors and enhanced control at the edge. Development of a low-level prototype (TRL three) based on a distributed system of low-cost sensors, useful for capillary monitoring, for real-time detection of local peaks of pollutants.
10. Bio-based industrial coating. Identification of a field of application for a technology related to the development of an anti-flame treatment with low environmental impact, with high added value in relation to the properties conferred to the final product, in order to obtain funding for the development of a proof of concept.
11. Goal-based sustainable dynamic personal asset-liability management (GBS-pALM). Identify credit access calls for the development of a software platform for fintech already in the form of a prototype at TRL four level, which is designed to offer financial advisory services ranging from optimal retirement planning to family planning.
12. Multifunctional platform for tracking people's movements based on wearable sensors for IoT.
13. Wearable sensor for fast and accurate measurement of Radon concentrations in a room.
14. Continuous blood pressure monitoring by introduction of implantable RFID tag sensor.
15. Electronic systems for monitoring brain activity consisting of a matrix of LEDs and wearable sensors.
16. System based on 3D technology for diagnosis and treatment of amblyopia and other visual diseases.

17. Off-grid charging station capable of recharging electronic devices without connection to the electricity grid using photovoltaic modules and a micro wind turbine.

In the following, the steps used to identify open problems from each case study are presented.

1. **Technology scouting** during which the candidate meets the researcher proposing an idea, investigating its novelty and originality on the basis of state-of-the-art results (scientific articles, patents and projects). The meeting is carried out through an interview aimed at collecting more information than previously presented at the TTO. The aim is to translate the idea according to a functional logic so that it can be better compared with state-of-the-art contributions. Moreover, in this phase, the entrepreneurial attitude of the researcher is also investigated. Then, the candidate autonomously carries out a technological screening of the idea, compares it in depth with state-of-the-art contributions and investigates its level of technological maturity. Figure 7 shows schematically the different phases of the technology scouting activity.

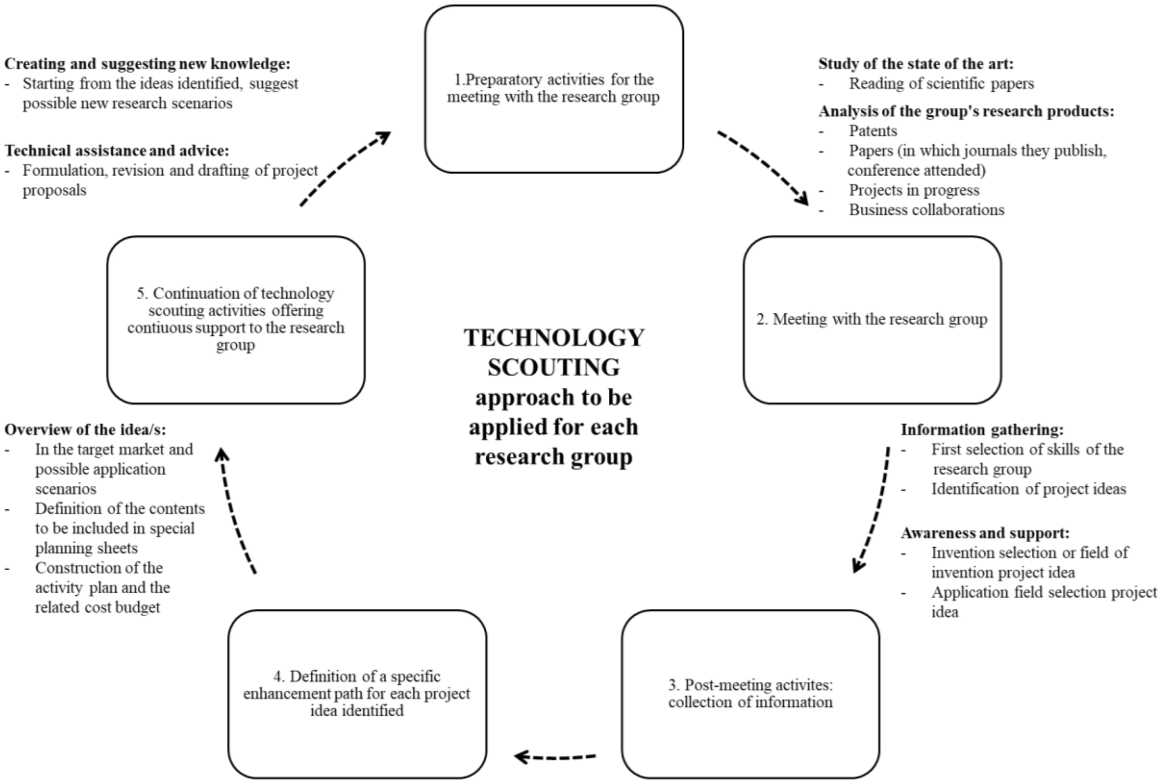


Figure 7. Outline of the approach used to conduct technology transfer activities.

2. **Checking intellectual property requirements** to understand the patentability margins of the proposed idea. The criteria considered are: novelty (the idea is not included in the state of the art), originality (the idea is not anticipated or intuitable from prior art), industrial applicability (the idea must be capable of being manufactured), lawfulness (the idea is not contrary to public order and morality). Here again, the basis for evaluation is the state-of-the-art documents of scientific articles and patents. This activity is very costly due to the large amount of data to be analysed, but can be facilitated by the introduction of automatic text analysis tools, such as those already mentioned above.
3. **Matchmaking with stakeholders,** proposing the idea to companies. This activity is based on identifying companies with business interests compatible with the idea. Warrant Innovation Lab, a consultancy specialised in access to credit, supported the candidate during this phase.
4. **Creation of the proof of concept** of the idea in collaboration with the company concerned.

5. **Commercial valorisation of the idea**, hypothesising the possible economic returns in the medium to long term.

3.2. Open problems from the operative context

The boundary conditions underlying this collection of open problems identified in the literature, however, do not consider several more practical aspects that can typically be found in the academia context. The limitation is that the contributions from the literature have idealised the analysis scenarios, considering only superficially some of the more practical aspects that can be crucial and with which a TTO grapples almost daily and that the candidate has had the opportunity to experience personally. The open problems from the operative context are summarised as follow:

- Delays due to administrative practice on the part of various academia committees responsible for evaluating the project activity to be transferred.
- Frictions between intra- and inter-departmental research groups in facing a certain project activity and in dealing with private companies in matchmaking activities.
- Deontological limits of researchers, established by legislation, in dealing with the protection of project activity to be transferred.
- Competitiveness of the technology transfer activity that a researcher can perform with the many other professional assignments, such as teaching, research, participation in conferences, institutional assignments.

For these reasons, the previously identified open problems were compared with the more practical ones encountered during work in the field of technology transfer.

In this Section, the results obtained from each of the case studies considered by applying the procedure described are presented.

- Difficulty of intervention in the evaluation of the idea by TTO members due to the excessive specificity and complication of the explanations provided by the researchers.
- Unclear perception on the part of the researcher about the protection that a patent can offer to the idea, as well as its real element of novelty. One of the causes is also the lack of training of researchers on intellectual property and the tools to recover knowledge from patents.

- Almost always, only the peculiar Function of the idea was tested, leaving aside the investigation of possible alternative uses.
- Difficulty on the part of the researcher in translating the operation of the idea into functional terms so as to facilitate matchmaking by identifying potentially interested companies.
- Initial tests of the idea and its first prototypes were conducted by the researcher only in specific application contexts, which are very well known to the researcher and where it is initially assumed that the idea can be developed.
- The researcher does not know the potential competing products for his or her idea nor the degree of market saturation regarding the possible introduction of his or her idea.
- Lack of knowledge, on the part of the researcher, of the industrial landscape in the relevant sector. In this way, the researcher is led to contact only a few possible buyers with whom he can more easily come into contact rather than those who are more strategic for the acquisition of his or her idea.
- Lack of industrial vision on the part of researchers who focus only on the more technical aspects of the idea, neglecting other requirements such as feasibility and marketing aspects.
- Usually, only a few experts in the field have evaluated the idea, producing similar and very specific judgements.
- The technology evaluation requirements provided by the researchers are assessed too subjectively.
- Lack of an economic and financial plan for the development of the idea which makes it difficult to compare it with competing products with a view to replacing them on the market.

4. Proposal: Information retrieval

In this Section, the method proposed by the candidate to address the open problems concerning Information retrieval identified by the literature (Section 2.1) and the operational context (Section 3) is introduced and explained.

In extreme synthesis, the method concerning Information retrieval (Russo et al., 2020) consists of four main steps about the application fields of a product by analysing the related documentary sources, with a predilection for patents.

The first step (Step 1.1, see Section 4.1) concerns the selection of the technology and the document pool from which to extract the technological properties of the product. (Step 1.2, see Section 4.2) Identify the Functions performed by the product, extracting and verifying them in a semi-automatic way from the patents. (Step 1.3, see Section 4.3) Semi-automatic extraction of product applications in patents starting from the Functions identified. (Step 1.4, see Section 4.4) Semi-automatic extraction of product requirements from the same patent pool and verification of them with experts in the field.

Figure 8 schematically presents all the steps and sub-steps of the proposed method.

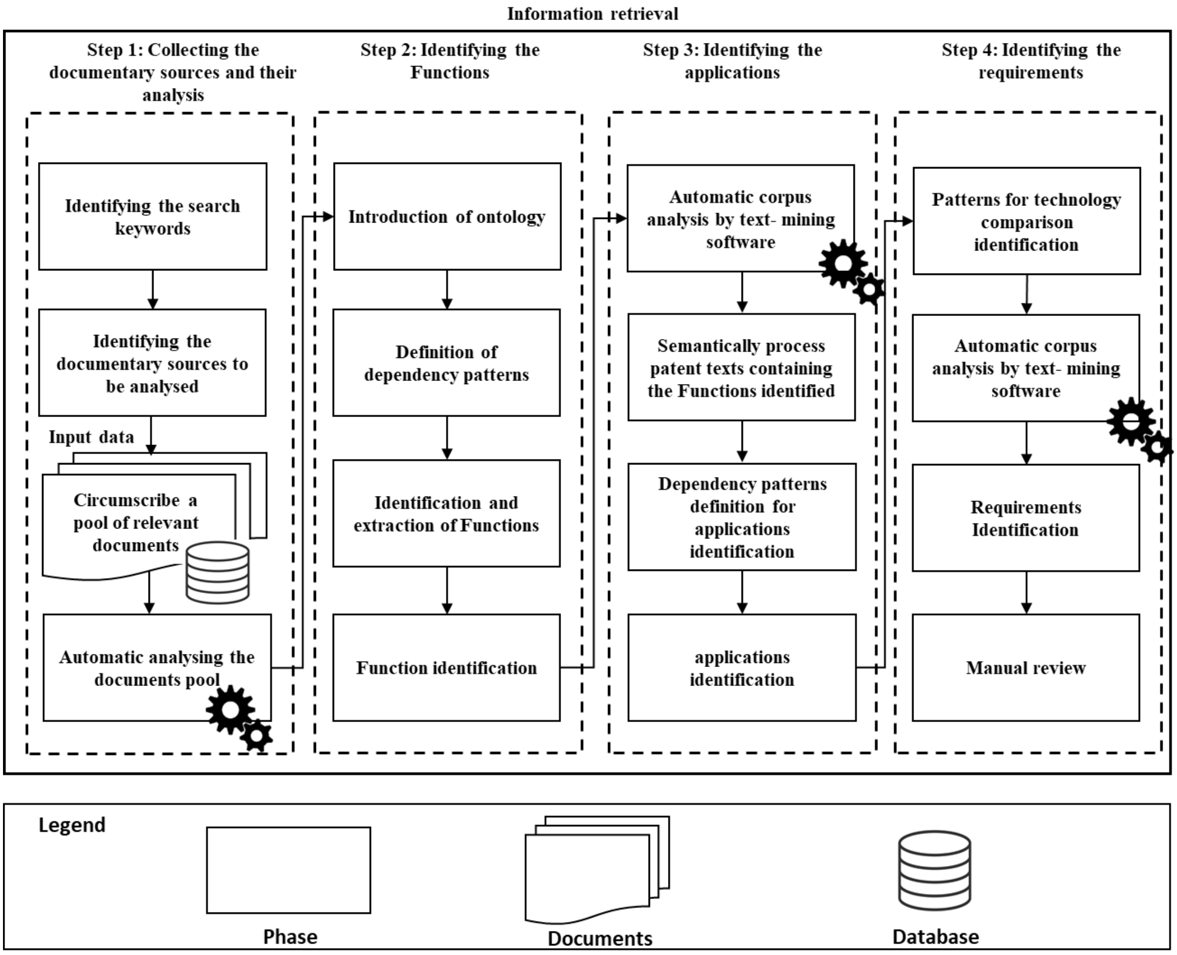


Figure 8. Overview of the suggested method.

In the following section, each step and sub-step of the proposed method is presented in detail.

4.1. Collecting the documentary sources and their analysis

The starting point of Information retrieval is the collection of documentary sources related to the considered product. This activity is structured in four sub-steps.

1. **Identifying the search keywords** through an interview with the researcher or entrepreneur, who works with the academia, proposing the product. The aim of the meeting is to understand how the product works in order to formulate search queries based on functional logic.
2. **Identify the documentary sources to be analysed**, from which the possible fields of application of the product will be extrapolated.

3. **Circumscribe a pool of relevant documents** to be analysed from all the document sources collected, using search queries based on the Function of the product.
4. **Automatic documents pool analysis.** This Sub-step consists of semi-automatically analysing syntactically and semantically the texts of the documents in the document pool in order to extract the application fields.

In the following, the different sub-steps are presented in detail.

4.1.1. Identifying the search keywords in order to formulate queries based on functional logic

Sub-Step 1 aims to support the understanding of technical proposals submitted by researchers or entrepreneurs to the TTO, by translating the presented idea from a generic or colloquial form to a simple, clear and functional logic. The objective is to identify the Function of the product.

This first Sub-step is essential for those conducting the interview so that they have a clear picture of the invention or project idea proposed in functional terms, that is, they can understand what is the main function that the product wants to achieve.

This awareness has to be guaranteed, at least to a basic extent, regardless of the level of technical competence of the interviewer regarding the scope of the idea and the presentation support used. The functional framing of the product is a fundamental step because it is the starting point on which the identification of the documentary sources on which the information extraction steps for technology transfer will be based.

4.1.2. Identify the documentary sources to be analysed

Sub-Step 2 consists of retrieving all documentary sources from patent, scientific and commercial databases that include information useful for the critical analysis of the presented idea, whether technological and/or legal.

This procedure requires extensive knowledge both of the documentary sources that will be identified, selected and used as input for the search, and of the tools (e.g. patent or scientific databases) that will be interrogated to retrieve knowledge about the product.

It is therefore important to be able to discern by documentary source in order to retrieve the necessary knowledge best suited to the case study.

In analysing patents, it is possible to find information about technological trends, design paradigms, opportunities, reveal risks and get decisive insight into the full value of the company's innovation assets. Patent databases are the tools that are used to collect full-text patent documents. These databases provide fast access to worldwide patent data. Sophisticated data searching tools are also available and the user can retrieve a lot of useful data, so much that it turns out to be much more than he can effectively read and analyse. Each patent has a standard structure with fixed sections: bibliographic data, classification codes, title, abstract, description, drawing and claims.

Patents, therefore, provide important information about technological advances of a product. The combined use of patents and scientific papers makes it possible to provide a more comprehensive perspective of exploration and not restricted mainly to the academic field of papers, but also open to developments in industrial research, with patents.

After identifying the most suitable documentary source to carry out the analysis, which varies from case study to case study on the basis of different factors, the tools that will be used to carry out the analysis will be presented.

Table 1 presents a schematic description of the main tools that will be interrogated through search queries to identify the documentary sources to be analysed. The tools are subdivided on the basis of the document source for which the analysis is carried out: patents, scientific articles and interrogating databases that collect documents pre-formatted a priori with a special dedicated and customised template. For each tool, the type of input data needed to query the database, the provided output and its quality is provided in a comparative perspective.

Table 1. Overview concerning the presentation and comparison of the tools used to identify the documentary sources to be analysed.

Tools to identify documentary sources	**Typology**	**Input**	**Provided output**	**Output quality**
Patent Databases: Espacenet, Patentscope, USPTO, Orbit Intelligence search patent database by Questel	Database	Categories (patent classification codes). Single keywords. Chained words throught the use of special operators (i.e. boolean)	Full-text or specific sections of patent (title, abstract, description, claims, draws, bibliographic information of inventors or applicants).	Ready solutions Raw and ready Ideas to be used as analogies
Abstract and citation databases: Scopus by Elsevier, Google Scholar	Database	Single keywords, Chained words throught the use of special operators (i.e. boolean)	Scientific papers (proposals + case studies)	Ready solutions Raw and ready Ideas to be used as analogies
Interrogating databases: AskNature by Biomimicry institute, DANE	Database built on a specific ontology (biomimicry taxonomy)	Single keywords, Chained words throught the use of special operators (i.e. boolean)	Examples	Ready Ideas to be used as analogies

Concerning the patent databases, Espacenet is the European patent database provided by the European patent office (EPO). It contains approximately 120 million documents, from 1782, concerning patents field with both the EPO office and national intellectual property offices in the rest of the world.

The World Intellectual Property Organization offers free access to Patentscope database: a collection of approximately 97 million documents including international Patent Cooperation Treaty (PCT) applications and patent documents of national intellectual property offices in the rest of the world.

USPTO is the United States Patent and Trademark Office database and it provides to user a full-text and image database containing only United States patent applications in full-text format on the day of publication.

Lastly, Orbit Patent Intelligence is a private database that contains the highest number of patents in the world, 130 million. The database is updated monthly and contains the full-text of all patent documents from all patent offices.

Scopus database combines a comprehensive, peer-reviewed abstract and citation database for scientific papers with augmented data and related academic literature in a wide variety of academic disciplines. Scopus rapidly locates pertinent and authoritative research, identifies experts and provides access to reliable data, metrics and analytical tools. The same can be said for Google Scholar.

Other tools presented in Table 1 concern the interrogating databases, for instance AskNature that is a well establish tools within the bio-inspired design toolset. Known for being the largest database related to bio-inspiration, the tool aims at initiating pathways between natural phenomena, living organisms presenting such phenomenon and potential experts of the considered organisms. DANE is a functional modelling has been a major way of describing investigated systems for the bioinspired design process.

4.1.3. Circumscribe a pool of relevant documents

The Sub-step 3 consists in identifying the pool of pertinent documents from which to circumscribe a pool of relevant documents that will be used as a starting point for the next phase of Information retrieval.

To perform this sub-step, the patent database is the most appropriate tool because it contains technical properties and technological trend of a given product. It is possible to choose to work on the entire patent dataset, which contains around 130 million documents, or select specific statistically relevant samples to perform the analysis, such as the international database (Patentscope), or the public offices database, such as USPTO, that contains fewer documents.

Once the documentary sources and the tool to collect the database have been identified as the starting point of the research, the methodology described in Sub-step 3 consists of a manual first screening of the collected documents.

This procedure consists in translating, by means of search queries, the information identified during the technology scouting meeting, reworked in a simple, clear and functional logic on the basis also of what has been learnt about how data works and how it is structured within the reference databases.

The objective is to define a first large set of documents to gather the most of state of the art about the targeted topic. The size of the first pool of documents should be as large as possible, as long as it is relevant to the targeted technology. The size of the patent sample is related to the level of innovativeness of the technology and varies according to the case study.

If some technology does not present a state of the art within the patent literature, the search is adapted in databases of scientific articles. One problematic issue is precisely the size of the pool. The size of the extraction does not directly interfere with the quality of the analysis, but it does lengthen the time required.

The system that will be presented in the next sub-step works through an advanced lexical analysis, in order to extract information from the pool it must first be processed. The processing time and all subsequent steps are directly proportional to the size of the pool.

Consequently, it is advisable to repeat the search queries by excluding all those patents that marginally mention the product. This can be done by adjusting the syntax of the keywords searched, inserting operators, introducing Cooperative Patent Classifications codes (CPC) into the search, searching within specific patent fields (e.g. title, abstract, claims) and limiting the time interval to the early priority date, i.e. the filing date of the patent application.

In this way, the final patent pool is defined, which will be the subject of further analysis. The methodological steps of sub-step 3 are described in the schematic representation in

Figure 9 that provides an overview of the selection pool phase regarding relevant documents.

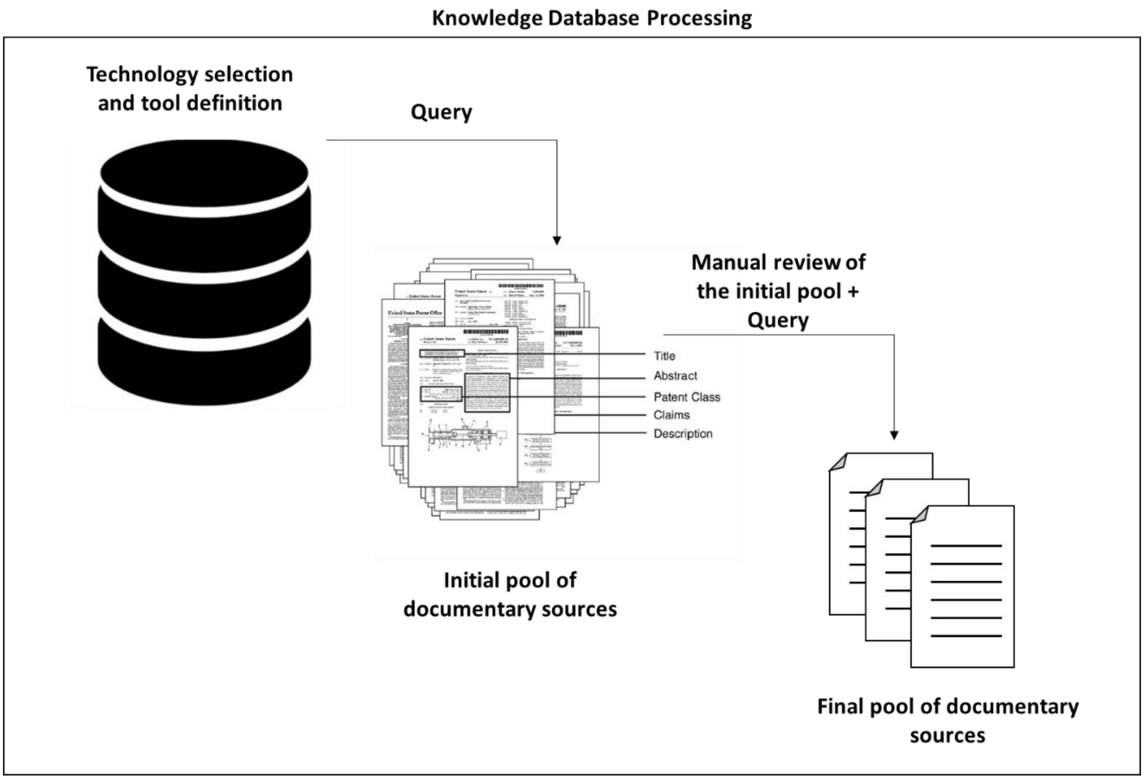


Figure 9. Overview of the Sub-step 3: circumscribe the pool of relevant documents.

Starting from the final pool of documents identified, it is necessary to extract the identified documents from the starting database. Extracting the document pool is time-consuming and dependent on the tool used. The Orbit Patent Intelligence database allows data to be extracted in different formats (with a limit of 30,000 documents at a time in full text or the equivalent in terms of words for specific sub-sections determined ad hoc).

Patents that are not written in English are automatically machine translated into English. For scientific papers, the Scopus database also allows the extraction of articles in different formats.

4.1.4. Automatic analysis of the documents pool

The automatic analysis of collected documentary sources is not an obvious matter. Despite it have been a greatly developed during the lasts years, the Information retrieval from patent texts is yet a difficult task due to different reasons. Syntactic structure of the sentence in a patent text is complex from a syntactic perspective, in particular for claims structure, without an ordered and deterministic organization of the parts (Wang et al., 2015). The sentences are much longer than other written works (e.g. scientific papers), with several parts of the same type, e.g. two subjects or two predicates, which complicate the functioning of common text mining tools (Srinivasa-Desikan, 2018). The high presence of technical neologism, heterogeneous language due to the mix between technology and legal jargons makes it difficult to match with pre-loaded dictionaries in text-mining tools (Shinmori et al., 2003).

It is therefore essential to overcome these limits by using new tools and methods, which take into account the problems and solve them using innovative technology to identify information from large amounts of textual documents.

A fundamental contribution to this activity has been made by Trix srl, a start-up from the University of Bergamo, which has developed a software infrastructure capable of automating many of the processes stated here and gradually anticipated in scientific articles already published (Russo et al., 2020) or submitted to sector journals (Journal of Engineering and Technology Management, actually under review).

Trix srl was born from the collaboration of computer experts and patent specialists with previous varied professional experiences. It is a spinoff of the University of Bergamo that has developed innovative solutions to perform automatic analysis in the technological field. The focus of Trix is based on the automatic and punctual extraction of data from textual sources mainly consisting of patents and scientific papers. The results are summarised in various types of infographics aimed at decision makers in different company functions such as R&D and marketing. The internal workflow involves an initial user request that results in the creation of a document database, which is then analysed by artificial intelligence systems and ends with the generation of a semi-automatic report based on the initial requests.

The tool developed by Trix srl to search for technological features within patents for the benefit of the activities carried out by a TTO is a semantic search engine. After an initial test of the tool with theoretical case studies, it was applied to real TTO case studies.

This tool was selected because it allows a great saving of time resources, mainly because of its graphical interface that guarantees an immediate reading of the results obtained from technology forecasting, patent intelligence, competitor analysis and technology transfer.

The operation of the tool consists of semantic processing and was initially developed to search for SAO triads. At this stage of the search, using a semantic search tool allows one to reach a result that just a few years ago would have taken months.

In the past, patent classes would have been taken and classifications would have been developed based on them. Tools such as Orbit Patent Intelligence provide the ability to visualise by orders of magnitude the patent classes associated with a classification made by the Fraunhofer institute. These classes, however, number approximately fifty, a variety of distinctions too small to be truly relevant.

After uploading a pool of pre-processed documents in ".xml" or ".csv" format to the tool, a syntactic analysis is automatically conducted. The corpus text is divided into a series of single words, assigning a syntactic role to each of them. In this way, similar words with different meanings from a logical and syntactic point of view can be discriminated. Then, the tool performs an extrapolation of syntactic lemmas from the corpus to provide a list of features to be read. Moreover, the tool provides a list of sentences aggregated by their representative syntactic-semantic construction. Therefore, the results obtained must be checked manually and classified. In this respect, the tool automatically suggests some qualifying labels of the syntactic role of the words identified.

As shown in Figure 10, the software provides the user with a structure divided into subject, action and object. In this way, the user is guided in entering keywords as a starting point for performing the semantic search within the document pool (Phase 1).

The parsing procedure begins by analysing the unprocessed text. This procedure is composed of a set of algorithmic operations that enhance the input text with supplementary properties. In particular, the unprocessed text is converted into a sequence of individual words, called tokens. Subsequently, for each token, the parsing software generates a tag that represents the part-of-speech (PoS) of that token. In this way, the procedure becomes able to recognise similar words with different meanings (i.e. "mark" is a verb versus "mark" is a noun), the so-called disambiguation functionality. Afterwards, the software computes the correlations between the tokens that compose a sentence and codes a dependency graph of the sentence structure in the procedure.

The software recognises the syntactic roles of the keywords entered and processes the entire document pool by searching for all the sentences within the patents in which the keywords appear, e.g. “gas” as subject and “paralyse” as action. The results of this analysis are shown on the screen by syntactically subdividing the sentences found by subject, verb and object complement. Next to each sentence, the software reports the number of sentences within the patent pool that have the identified direct objects.

The second phase consists of manually checking the results provided by the software and selecting the most significant ones for analysis (Phase 2). Manual review is essential because semi-automatic review of technical documentation involves two categories of challenges. The first type is the one common to the processing of all documents written in natural language. Natural language is subject to polysemy (the property that a word must express multiple meanings) and synonymy (relationship between two lexemes with the same meaning). The second one is related to technical domain (terms, relationships, standards, etc.).

Once a sentence has been selected, e.g. “gas pyrolyse waste”, the software returns on screen a structure divided into subject, action and object, in the same way as Phase 1, but automatically filling in the direct object with “waste”.

In this way, (Phase 3) it is possible to increase the level of detail of the research or to find other Functions performed by the subject previously defined. Also in this case, a manual review of the results is still required.

Figure 10 schematises the functioning of the semantic search engine for extracting technological features by loading a pool of patent documents concerning a generic product into the system.

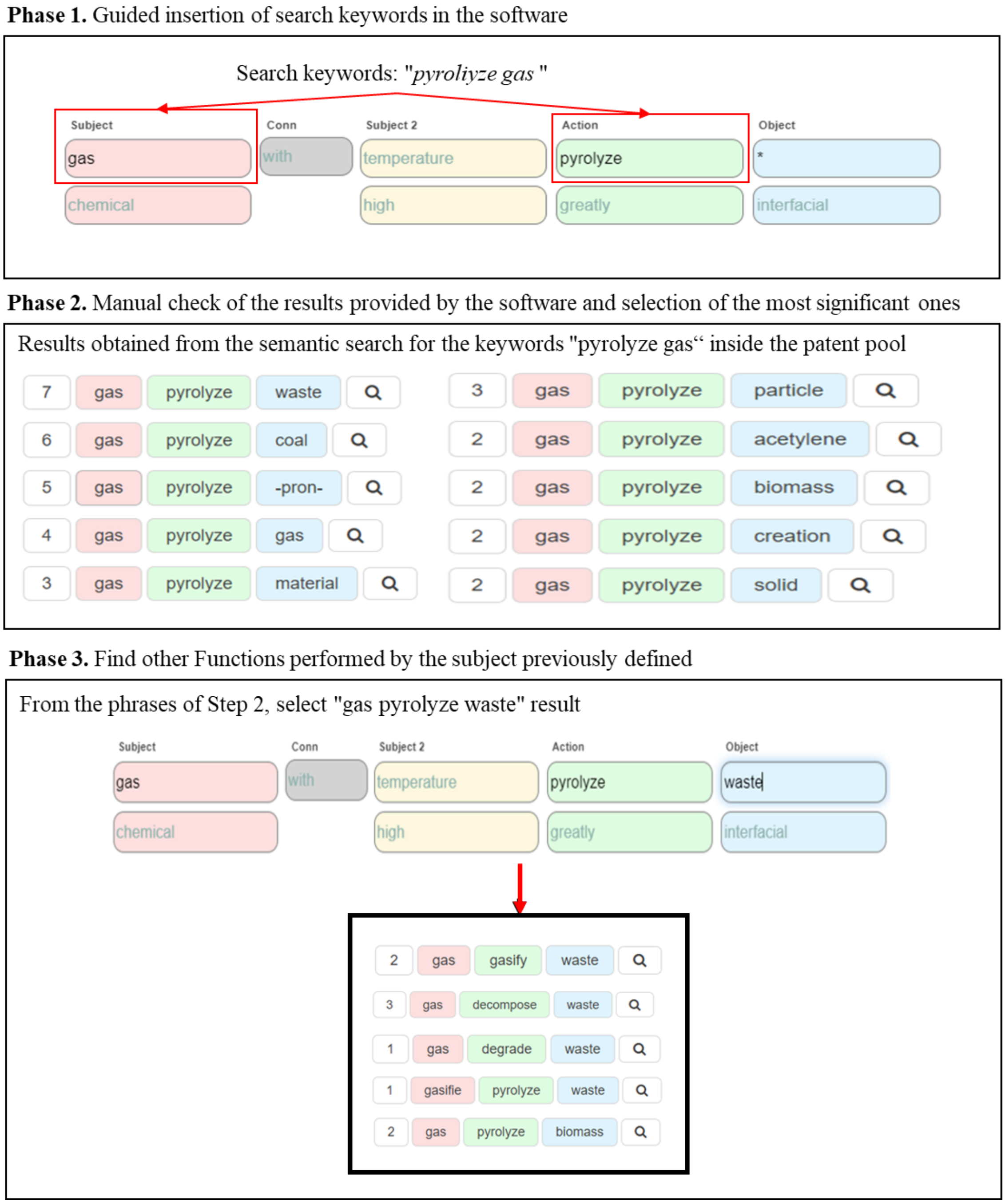


Figure 10. Schematic representation of the three steps related to Sub-step 4: automatically analysing the document pool. The presented procedure is carried out by using the semantic search tool developed by the spin-off Trix Srl.

4.2. Identifying the Functions

This Section explains how the Functions performed by the product may be identified semi-automatically from patents.

To do so, the method of identifying Functions is divided into a number of sub-steps. Sub-step 1 introduces the ontology used for the recognition of Functions. Sub-step 2, instead, presents the dependency patterns that are used for the extraction of the Functions from the text, using the semantic search tool. Finally, Sub-step 3 consists in the identification and extraction of Functions by means of dependency patterns.

4.2.1. Introduction of ontology for Function identification

This Section introduces the ontology used by the proposed method to identify Functions and applications.

The Minimal Technical System (MTS) model of TRIZ serves as the basis for this ontology, providing a definition of the Function of the product. This step constitutes the basis on which a problem solving activity is carried out, both in the traditional design and in the product design (e.g. Altshuller, 1984) than in other areas, such as eco-design (e.g. Russo and Spreafico, 2020; Spreafico, 2021).

In order to describe the functioning of a product, the MTS model considers four main elements to which it associates precise definitions.

- The Object is the entity that undergoes the action of the Technical system.
- The Product is the transformed Object.
- The Function is the transformation of the Object into the Product and can be described with the physical effect that is responsible for it.
- The Technical system is the name associated with the product. It comes into direct contact with the Object, according to a mechanical, acoustical, thermal, chemical, electrical, magnetic, intermolecular, or biological interaction and exercising the Function on it to transform it into the Product. It can be solid (e.g. a saw), fluid (e.g. a hot gas) or an electromagnetic wave (e.g. a laser). In turn, the technical system consists of several constituent parts. These are supply, transmission and tools.

Figure 11 provides a schematic representation of the Minimal Technical System model.

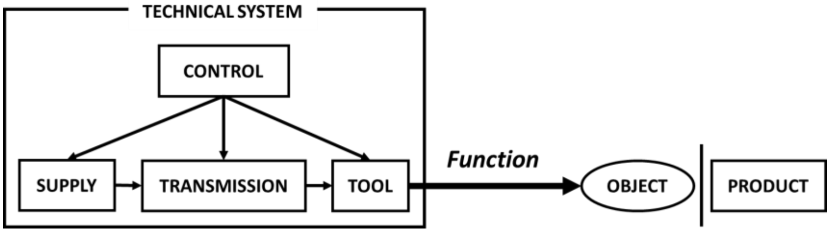


Figure 11. Minimal Technical System model (Altshuller, 1984).

4.2.2. Definition of dependency patterns for the extraction of Functions from the text

The extracted pool was processed using a Natural language processing parsing tool, as described in Section 4.1.1 of this dissertation. The software analysed the text by associating each individual word with its syntactic role. For the purposes of this research, the software is a tool that is used to perform a preliminary, but necessary, task for the semi-automatic extraction of information from the text. Information that will have to be reviewed manually and revised according to the ontology.

The starting hypothesis for defining dependency patterns for extracting the Functions from the text is that the different design elements (i.e. Function, Object and Technical system) have precise syntactic roles within the sentences of the documents analysed. Additionally, it is also assumed that there are a finite number of lexical forms (e.g. by, in order to) and nouns (e.g. method, mean, system) which are used recursively to link ontological elements at the syntactic level.

The next step is to interrogate the software in such a way as to extract the Functions from the text. In this regard, a search strategy consists of querying the tool using search queries based on the combination of verb and object complements. They are respectively the Function and the Object described in Figure 11. According to FOS method (as presented in Section 2.1.1), the first feature to be extracted is the list of Functions related to the product being studied.

This can be done initially through the use of SAO triads by placing the product under study as the subject and leaving the other action and object fields empty. In this way, the semantic software searches and returns all the sentences whose subject corresponds to the product. The sentences have to be checked manually.

Operatively, the task of mapping the sentence into a formal representation of its meaning is called semantic dependency parse and the tool that performs this analysis, called dependency semantic parser, is spaCy parser, which is an open-source library for Natural language processing, programmed in Python that can perform a syntactic analysis on a sentence.

The semantic dependency parser syntactically analyses a sentence through a rigorous representation of its meaning in the form of a directed graph with links between pairs of words represented by arcs. The processing of grammatical relations is done by adopting the rules shared by Standford typed dependency representation, designed to offer a clear description of grammatical relations to any user who can benefit from automatic text comprehension.

An example of how the analysis of the semantic dependency parser works is provided in Figure 12, which shows the results provided by spaCy parser concerning a random sentence.

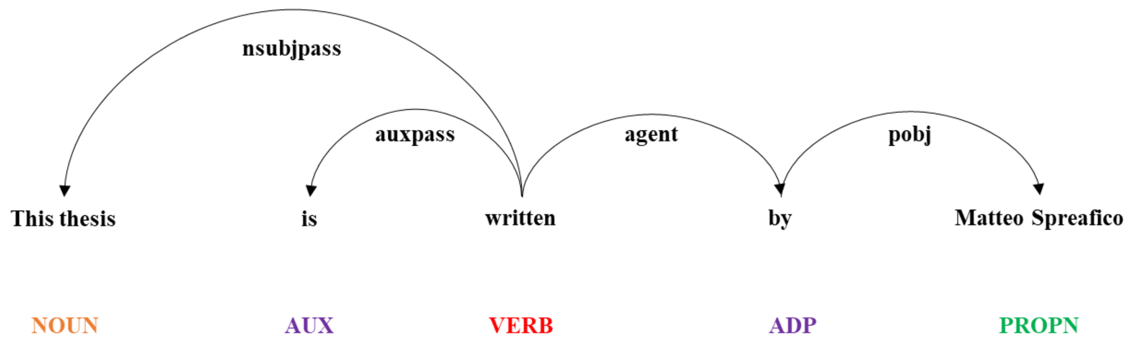


Figure 12. Automatic syntactic analysis conducted by spaCy dependency parser of the sentence "This thesis is written by Matteo Spreafico".

In the example reported in Figure 12, the phrase "This thesis is written by Matteo Spreafico" is analysed by spaCy parser which provides a graphical representation regarding the syntactic roles of the words and the relations between them. The dependencies identified, according to Stanford typed, are reported below:

- nsubjpass is a passive nominal subject;
- auxpass is a passive auxiliary;
- agent modifier used for passive verbs;

- pobj is the object of a preposition.

The main limitations with regard to parsing aimed at identifying functions are due to the presence of multi-words and compounds, which extend the length of the sentence by making the syntactic relationships between words less visible.

The use of an approach based on SAO triads makes it possible to identify all sentences in which the verb syntactically follows the subject corresponding to the inserted product. However, not all the verbs found are interesting for a technology transfer activity. The novelty of this article lies in the extension of the search not only to SAO triads but also to other semantic relations to be searched in combination with a dependency parser.

For this purpose, a dependency parser should be able to recognise, among the verbs identified, only the functional ones, for instance those verbs that imply a change of parameters on the Object they refer to. This activity requires a filtering of the list of results by identifying recursive patterns in the text through the use of special language libraries that classify verbs into categories and select only the most technical categories.

A structured procedure was followed to determine the dependency patterns linking the elements of the defined ontological model (i.e. Object, Product, Function undergone, Function performed, Technical system) within the sentence and which can be used to extract them automatically.

As a first step, all the scientific articles in the literature proposing generic dependency patterns based on SAO triads were collected and studied. These dependency patterns are typically used to extract information that has a certain syntactic role within the sentence and are not specifically related to the extraction of Functions from text. The ontology of the MTS model can, instead, be or not used to attribute also an ontological role to certain elements of the sentence.

The generic dependency patterns collected from the literature all refer to the analysis of single sentences and serve to link together two or more syntactic elements that play a key role in gathering information about a technical system. These dependency patterns were derived from a selected set of scientific publications. They were obtained using Google Scholar, by entering the terms “dependency pattern”, “dependency syntactic pattern”, “syntactic pattern”, “parser for pattern extraction/identification”, “syntactic parser” as search queries. Among the more than 250 documents, only those actually claiming to use dependency patterns for information extraction from text corpora based on syntactic analysis were manually isolated within title and abstract.

At a semantic-ontological level, in some of them, references to the MTS model already appear, albeit partial and relative to its canonical version to define relations. In other cases, specific verbs (e.g. "include") or constructs (e.g. "part of") are used to search for links between elements (e.g. component-assembly), or the same elements may have grammatical roles, e.g. hyponym and hypernymy to search for the same relationship.

At the syntactic level, some dependency patterns have associated elements with a certain role, e.g. subject, direct object or verb. Moreover, the classical SAO approach is able to find all verbs that are related to a given technology, however not all verbs are interesting for technology transfer.

The results obtained from this study are presented in Table 2. All the studies displayed refer to the syntactic analysis of the single sentence and, for each pattern, a description of its use, some examples and its source are provided.

Table 2. Results from literature search of the retrieved semantic relationships (dependency patterns) to be searched in combination with a dependency parser.

Patterns	**Descriptions, “examples” and (sources)**
{subject}[Technical system] + to, for, can, as, by, of, used to, used for, should, to obtain, … + {verb}[Function]	The subject of the sentence is associated to the Technical system. The verb is associated to the Function, e.g. “Fabric to heat” or “Fabric to dry” (Russo et al., 2020)
{subject}[Technical system] + increase, decrease, ameliorate, enhance, … + noun + of + {direct object}[Object]	The noun is a parameter of the object that is also the Object at the ontological level, e.g. “Radiations increase temperature of steel” (Russo et al., 2020)
{subject}[Technical system] + {verb}[Function] + {direct objectj}[Object]	A SAO triad associated to TOP model without the presence of the Product, e.g. “Water removes filth” (Goldfire Innovator, WO2010/105214; Cascini et al., 2004; Moehrle et al., 2005)

subject + activate, inhibit, … + (consist of, lead to, release, release in, for) + direct object	Identifying entities (subjects) that perform a predetermined set of actions on other entities (direct object) in biological corpus text, e.g. “Aminoacid activates protein” (Ciaramita et al., 2005; Cimiano et al., 2006)
noun_1 + change, increase, decrease, dependence, generate, act, cause, … + noun_2	Noun_1 and noun_2 are respectively a physical effect to be determined and a parameter, e.g. “Freezing change temperature” (Korobkin et al., 2017)
subject + such as, and other, including, is a, is the, the, of, is, as, by such, … + direct object	The subject is a part or a component of the Object and/or backward, e.g. “box including mouse, basement and building” (Etzioni et al., 2004; Berland and Charniak, 1999)
noun_1 + verb + noun_2	Noun_1 and noun_2 are respectively a hyponym and a hypernym, e.g. “snakes are reptile” (Ogata et al., 2004)
such as, as + noun 1 + or, and, or other, another + noun 2	Noun 1 is hyponym and noun_2 is hypernym, e.g. “such as (as) bruises or (and, or other, another) injuries (Hearst, 1992)
noun_1 + create, make, produce, differentiate, separates, distinguish, cut, reduce, trim, comprise, focus, include, be-capable, arrange, extend, be-adapted, perform, in combination with … + noun_2	The pattern is to help understand whether noun_2 can be a part or component of noun_1 (Ferraro and Warren, 2011; Wang et al., 2015)

The dependency patterns addressed in this section of the dissertation were chosen only where there is a relationship with the product under study, in the same sentence, in order to increase the probability of identifying both Functions and Objects.

In Table 3 are reported, as an example, the semantic relationships to be searched in combination with a dependency parses used to conduct the analysis with the aim to find the Functions. The patterns shown are only a sample of those semantic relationships which achieved the best outcomes of the several reports that were examined.

Table 3. Dependency patterns list for the identification of Functions in the sentence of a text. For each of the, several examples from the patent text are provided.

Dependency patterns for Functions identification	Related sentences (examples) from patent text
1. To + verb	[…] **to cut** TFT glass compositions. EP3274306B1 […] **to cut** tissue US10555753B2 […] **to inhibit** transmission US9950165B2 […] **to emit** a first color of light ES2709374T3 […] **to transmit** radio frequency US10554052B2 […] **to increase** erythrocyte RU2732229C2 […] **to kill** bacteria US8324595B2 […] **to deactivate** pathogens US9700642B2 […] **to detect** fluorescence emission JP2019146591A
2. For + verb	[…] **for burning** coal RU2482389C2 […] **for engraving** the metal cylinder surface US8048250B2 […] **for drying** botanical items US9739532B2 […] **for evaporation** an organic material KR101927925B1 […] **for desiccating** sera, biologicals and liquid substances US2345548A […] **for draining** bodily fluids AU2019216677B2 […] **for amortizing** packaging material CN109100223A […] **for splitting** sheets metal US20210101308A1 […] **for gripping** edible bird's nests US20180325084A1
3. Of + verb	[…] **of detecting** smoke TWI596576B […] **of grasping** ceiling-floor US20180325084A1 […] **of clinging** synthetic polymeric microfibers US3916447A […] **of fastening** a cage US10094896B2 […] **of fastening** a wall panel US10358828B2 […] **of colouring** a pre-sintered dental restoration US10226313B2 […] **of transmitting** a frame US10045298B2 […] **of receiving** a frame US10045298B2 […] **of burning** cigarette filter CN108113051B

4.	Can + verb	[…] **can activate** a light source US10303239B2 […] **can enable** field generator coils US10063846B2 […] **can disable** an alarm US10687715B2 […] **can detect** fire JP5707483B2 […] **can read** a plurality of memory cells US10811104B2 […] **can incorporate** bear vibration CN209085657U […] **can monitor** an IVI parameter CN106573633B […] **can track** a user's physical activity US10872540B2
5.	By + verb	[…] **by irradiating** a component such as metal JP2018020378A […] **by heating** thin film US9831082B2 […] **by washing** detergent US9926520B2 […] **by pasting** side glass CN102051132B […] **by melting** snow US20170027024 […] **by heating** drying apparatus WO2020/015278 […] **by wrapping** tires CN105706525 […] **by cutting** IR emission DE202009003858 […] **by burning** coatings TW201024488
6.	Used for + verb	[…] **used for connecting** earplug CN206150698U […] **used for wear** socket connector CN206150698U […] **used for light up** green red light illuminant CN206150698U […] **used for melt** sheets US10858582B2 […] **used for cover** lay film JP6717512B2 […] **used for targeted** imaging of tumours AU2017203340B2 […] **used for charging** system JP6320434B2 […] **used for charging** lithium ion battery JP6320434B2 […] **used for restoring** interactive device
7.	Used to + verb	[…] **used to set up** wireless connection US10255058B2 […] **used to deploy** changes US10255058B2 […] **used to treat** US20200171304A1 […] **used to evoke** response US20200171304A1 […] **used to tune** capacitors JP6771616B […] **used to adjust** capacitors JP6771616B

		[…] **used to measure** analyse concentration US10188334B2 […] **used to define** the frequency of a Helmholtz resonator US10343102B2
Other dependency patterns identified		
8.	Should + verb	[…] **should sustain** plasma US8969841B2
9.	As + verb	[…] **as emitting** laser pulse JP6101943B2
10.	Used as + verb	[…] **used as** cooling agents RU2745616C1

4.2.3. Identification and extraction of Functions from text using dependency patterns

By parsing the text of the patent, a very accurate list of verbs is automatically extracted without the user having to be an expert in the subject matter. This is possible thanks to the improvement of parsing engines brought to several software packages that are more efficient in terms of both the effectiveness in identifying syntactic forms and the speed of text processing.

The definition of a unique set of dependency models used for the extraction of Functions is a task that required several attempts because the tool analyses the text and assigns syntactic roles to sentences, but does not recognise Functions or other ontological parts of speech.

To clarify the foregoing, consider for example the Functions extracted through the analysis of the text relating to the product “heating fabric”. The majority of them are related to verbs related to actions that are made to produce or modify the fabric itself, while the objective of the dissertation is to identify only those actions in which the fabric is able to produce on a third object and on which the enabling technology (heating) has a direct relevance. More precisely, we can study how the heating fabric can dry, melt or produce radiation on another object due to its heating power.

At the same time, the winding functions are excluded as they are not relevant to the heating technology. Compacting, welding, folding are also excluded if these functions explain how the fabric is executed instead of the purpose for which it is designed.

It is therefore advisable to manually reorganise the Functions found according to the ontology introduced. Therefore, it is an objective to be able to discriminate between Functions and physical effects where only the former will be used to search the field of applications in the next section of the proposal.

As technology feature extraction using the dependency pattern approach is new in the literature, a comparative analysis with other approaches to technology feature extraction using SAO triads is required.

The comparative analysis is carried out using both the dependency pattern approach and the SAO triad approach. In the course of the PhD activities, several analyses were carried out to quantify the goodness of results obtained with the two approaches. In order to demonstrate the effectiveness of the approach, an example concerning heating fabric technology will be presented.

In order to have manual control over the results obtained to perform the recall calculation, a random sample of patents with a small sample size was considered. The sample includes 1000 patents and was built by querying the Orbit Intelligence patent database. The results obtained present, in title and/or abstract, the keywords "heating fabric".

After uploading the sample into the syntactic analysis tool, the SAO analysis was carried out where the Subject is heating fabric. The aim is to identify all action verbs that syntactically follow the subject (e.g. the heating fabric changes the form [CN107587234], where heating fabric is the subject, changes is the verb and the form is the direct object).

By repeating the analysis on the whole sample of documents, all the verbs obtained through the SAO approach were extracted. Similarly, the system was interrogated using the dependency patterns previously presented (in Table 3) and the analysis was repeated for each of them, extracting the action verbs each time.

The verbs obtained were overall reviewed manually and filtered based on the MTS ontology, maintaining only the Functions. Finally, the recall index was calculated.

The results of this analysis are presented in Table 4 in which the recall index calculated by considering the SAO technique with respect to other semantic relations on an analysis sample of 1000 documents. Recall is calculated on functional verbs only.

Table 4. Comparison between different semantic relations considering a sample of 1000 patents. The results are related to the recall index obtained comparing the Functions obtained by the SAO approach and the other semantic relations. The results provided are manually revised.

Dependency parse relations	**SAO**	**TO**	**FOR**	**CAN (indirect)**	**AS**	**BY**	**OF**	**USED FOR (indirect)**	**USED TO (indirect)**
Recall	37%	44%	21%	58%	9%	27%	16%	10%	14%

As shown in Table 4, the Functions that have been extracted using the SAO approach account for only 37% of the whole Functions identified. The rest of the Functions that could be extracted were obtained by applying the new semantic rules based on dependency patterns. These results suggest that, in order to be able to identify all the functions of a product, an approach that involves the combined use of the new semantic rules and SAO should be adopted.

Finally, Figure 13 summarises, in the form of an infographic, all the steps presented in Section 4.2 for the identification of the Functions: the introduction of ontology for Function identification the definition of dependency patterns for the extraction of Functions from the text and the identification and extraction of Functions from text using dependency patterns.

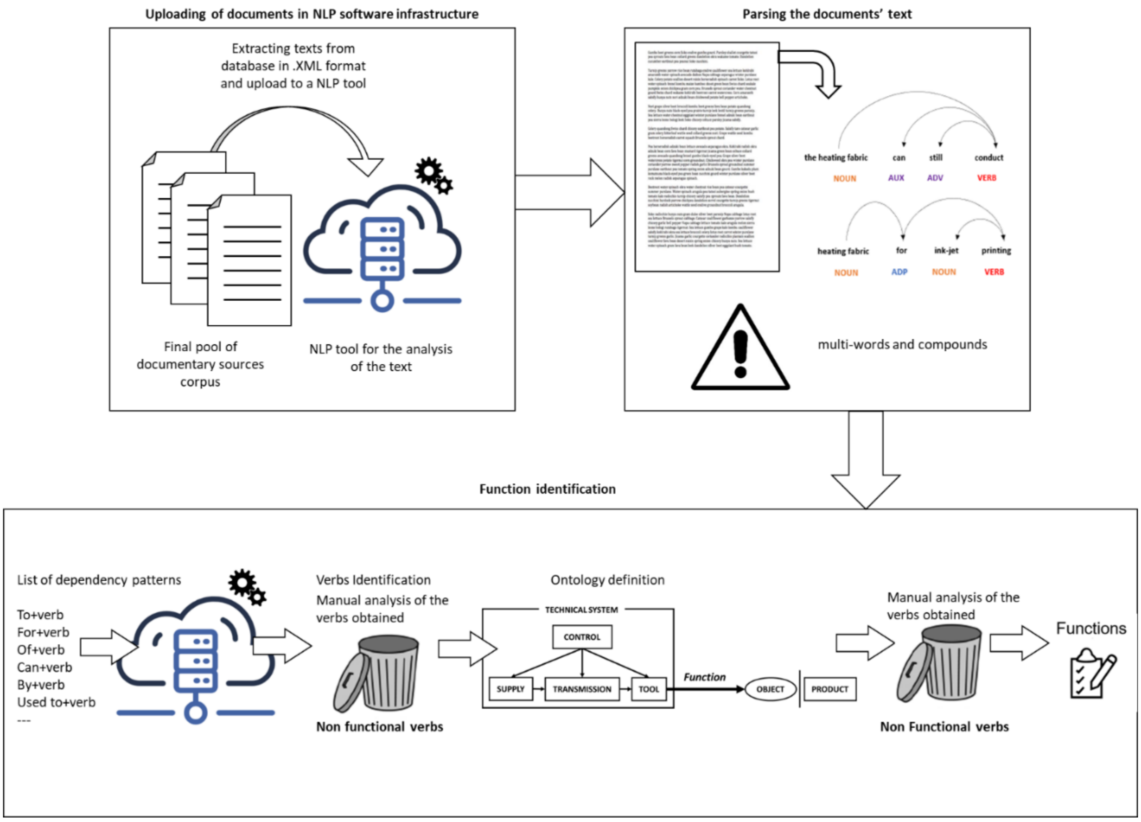


Figure 13. Schematic representation of all the steps taken to identify Functions from the text.

4.3. Identifying the applications

The next step is the identification and subsequent extraction, after appropriate manual review, of the applications.

From the point of view of technology transfer, the identification of fields of application is an extremely important aspect because it enables to suggest to the researcher/entrepreneur all the fields in which the product could be applied.

In this way, it is possible to implement strategic actions in order to identify new business opportunities in which investment can be made, in the case of contact with an entrepreneur, or to identify competent industrial professionals interested in investing and collaborating in the practical implementation of the product or the technology.

The starting point for carrying out the analysis is the list of Functions extracted in the previous step and the procedure, from an operative point of view, is similar to the one carried out for the extraction of Functions (Section 4.2).

A consideration regarding the nature of the text in which the analysis will be conducted. Since one is interested in extracting products, parsing of patent documents is recommended. The reason for this assertion is that all products described in invention patents must meet certain patentability criteria, in the absence of which a patent cannot be granted. Among the various criteria that must be met are novelty, originality or inventiveness and industrial application. A patent therefore protects an invention that is not understood and does not clearly appear in the state of the art, presents an inventive and creative process that is difficult to deduce from what already exists and, finally, can be manufactured or used in any kind of industry.

Another consideration regarding the applications identified is that different applications are associated to different Functions, i.e. the application "heating mattress" is associated to the Functions "dry" and "heat". At the same time, also a same Function may appear in multiple domains.

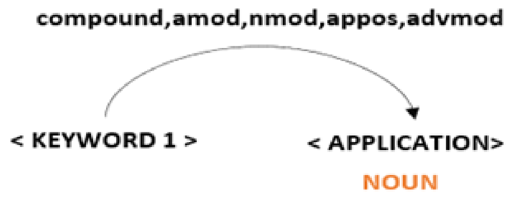
To automatically extract applications from the text, syntactic and semantic analysis is carried out by means of further new semantic rules that will constitute the dependency patterns. Dependency patterns are created based on the list of previously identified Functions.

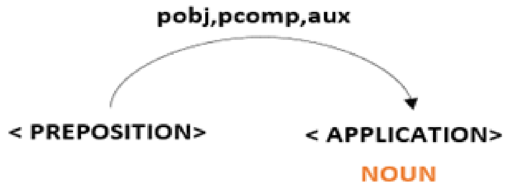
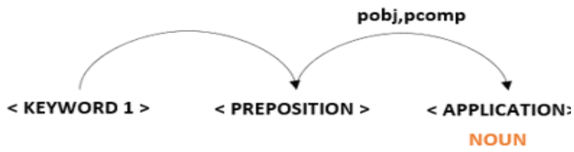
Also in this case the SAO technique is integrated by other dependency patterns. An additional set of semantic forms, embedded in a set of dependency patterns processed by syntactic parser specifically designed for the identification of this target is provided in Table 5.

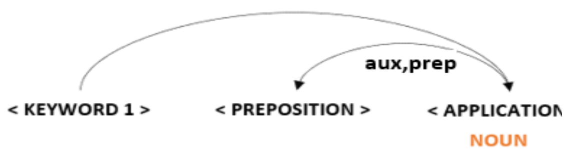
For each function, a routine is launched that takes advantage of the provided dependency patterns list to identify the applications. Also in this case, no sector-specific expertise is required to obtain the final list, but knowledge of the syntactic and semantic relationships of the sentences composing the patent text and ontological knowledge is necessary in order to identify the correct applications.

Table 5 provides the semantic relationships to be searched in combination with a dependency parses used to conduct the analysis with the aim to find the applications. The patterns shown are only a sample of those semantic relationships which achieved the best outcomes of the several reports that were examined.

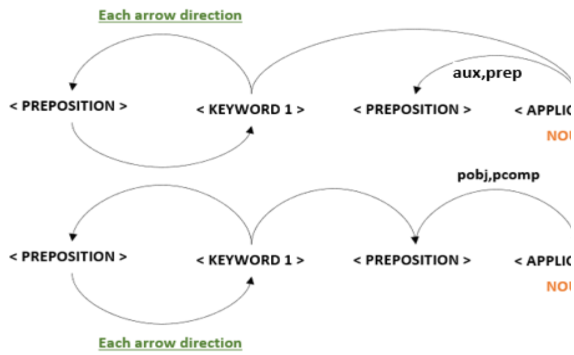
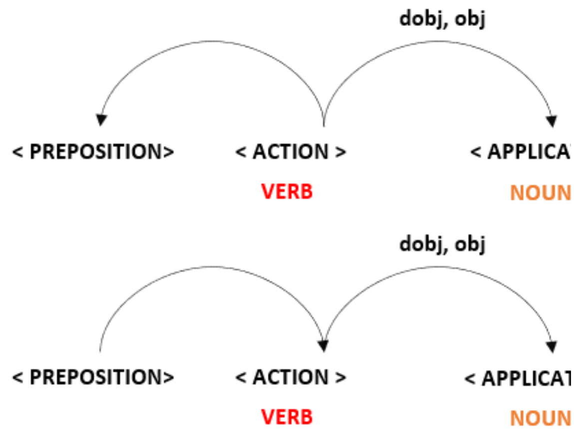
Table 5. Dependency patterns list for the identification of the applications in the sentence of a text. For each of them, examples from the patent text and the relative dependency parse visualization provided by spaCy parser is presented.

<table>
<tr><th>Dependency patterns</th><th>Function</th><th>Related sentences (examples) from patent text</th><th>Dependency parse visualization</th></tr>
<tr><td>As + noun</td><td>Protect</td><td>Polarized lens or light-attenuating lens protects airplane cockpit display as flight deck KR101822728 B1</td><td>


</td></tr>
<tr><td>To + noun</td><td>Prevent</td><td>Prevent fire to a room, duct DK1521617T 3</td><td></td></tr>
<tr><td>Applied as + noun</td><td>Secure</td><td>System to secure a maneuver to be applied as RE plasma generator US10854431 B2</td><td>


</td></tr>
<tr><td>Applied for + noun</td><td>Settle</td><td>System to settle a maneuver to be applied for a motor</td><td></td></tr>
</table>

		vehicle FR3046859B1
Applied to + noun	Detect	**Detecting** tap input **applied to touch sensor** in the doze mode US10095353 B2
Used as + noun	Remove	[…] **remove** residues from OB-folds **used as scaffolds** for engineering new specific binders JP6684761B2
Used for + noun	Dry	[…] the **dryer used for textile material web** EP2694900
Such as + noun	Incorpora te	[…] these devices could be **incorporated** in different arrangement **such as railed devices** US10617906 B2

Insert in / into / inside + noun		[…] analyte sensor **inserted into a sheath**	
As well as + noun	Melt	[…] containing a flexible heating fabric sheet [..] the snow **melting** surface **as well as mat** for stairs JP2000328509	
To obtain + noun	Sterilize	[…] sterilize a paste body **to obtain toothpaste** containing flos Lupuli extract CN110755277A	

The parser identifies a series of sentences considered relevant because of the presence of the Functions and dependency patterns identified following the observation of many different case studies. Also in this case, a manual filtering phase of the results obtained follows.

Finally, Figure 14 summarises, in the form of an infographic, all the steps presented in Section 4.3 for the identification of the applications.

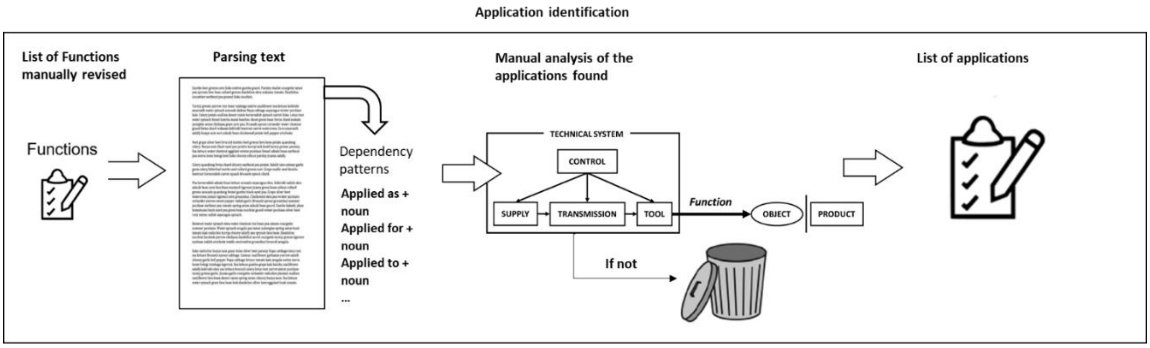


Figure 14. Schematic representation of all the steps taken to identify applications from the text.

4.4. Identifying the requirements

The list of applications identified in the previous step, obtained semi-automatically by Natural language processing tools from documentary sources thanks to the efforts aimed at identifying dependency patterns, represent all the possible fields of application of the product for which there is a direct repercussion documented by scientific articles and patents.

From a technology transfer perspective, it is appropriate to assess which of the identified applications is potentially most suitable for transferring one's own technology and directing future business actions.

On the basis of what has just been stated, it is appropriate to define a set of requirements, qualifying technical and descriptive properties of the reference applications that will be used as comparison factors to assess the technical convenience of substituting applications between two competing technologies.

The definition of technical requirements varies from technology to technology and from product to product. Generally, this activity of defining requirements is carried out by experts in the specific sector and, therefore, bound to the subjectivity deriving from their degree of operational experience or from their education on the subject.

In order to limit as much as possible subjectivity in the definition of technical requirements by experts in the field, whose judgement might not take into account the complexity of the determining properties of a product, it was decided to refer to semantics in order to define a set of rules aimed at extracting technical requirements from the text.

Natural language processing tools can help in identifying also requirements to be used as comparison factors between two competing technologies. In line with the work done so far, also for the requirements collection a new set of terms used as models to be managed with Natural language processing tools is proposed.

The first step consists in selecting the pool of documents to be analysed, which may be the same as in the previous methodological steps and, therefore, related to the product under study, or a purposely selected sample. In any case, the dependency patterns that will be identified and aimed at requirements extraction follow a series of rules that make them suitable, at present, for requirements extraction regardless of the technological field.

In order to formulate these rules for defining dependency patterns, it is necessary to study, from other work both in the state of the art and carried out by the candidate during the dissertation work, how the requirements can be expressed.

For example, a requirement can be expressed as a couple of a technical parameter (noun) and a general action, for instance: *increase, decrease, ameliorate, enhance.* Parameters can also appear associated with *proof, anti, less.* Requirements can be appearing as a list of nouns ending with *–bility,* better if associated in a patterns with *"lack of -bility".* Unfortunately, they can be hidden in many others linguistic forms, maybe impossible to map out in full; however, this set of expressions, launched on a sufficiently significant pool, is conceived for extracting almost all the desired requirements.

Evidently, the more complete the pattern network, the more reliable the final evaluation will be. Each requirement can be composed from a list of patterns that can be taken from, for instance: type of product, type of material, objective to be achieved, problem, parameter to be measured, parameter to be improved, product-proof, objects of a specific function, functions that the product receives.

Table 6 presents some of the qualifying characteristics of a product that have to be taken into account for the identification of requirements.

Table 6. Thesaurus of features to be considered for requirements identification and related examples. The examples are deliberately generic in order to provide greater clarity in defining the technical requirements.

Features to be considered for requirements identification	**Examples of the features considered for requirements identification**
Goal to achieve	• Increase flexibility • Decrease voltage • Reduce thickness • …
Problem to be faced	• Replace material easily and without high costs • Ability to maintain temperatures in a predetermined range • Maintain the capacity of the material to slow the consumption of a material • …
Product type	• Thermal insulation panel • Nanopourous materials • Resistant to compression materials • …
Kind of material	• Silica • Carbon • Graphene • …
Parameters to measured	• Wight / length • Temperature / heat precision or dissipation • Wave emission • …
Parameters to be improved	• Resistance (of corrosion etc.) • Temperature / heat precision • Thermal inertia • …
Proof	• Wind proof (textiles)

	• Rain – snow – proof (clothing) • Cold proof (thermal jacket) • …
Technical functions	• Strength • Durability • Hydrorepellency • …
Agents involved	• Low-molecular mass agents • Good, trade agencies • Import / export, wholesale • …

In general, although this approach provides a huge list of parameters, the final selection of the most relevant requirements for comparison is preferable to be validated by an expert in the field, in every steps of the analysis.

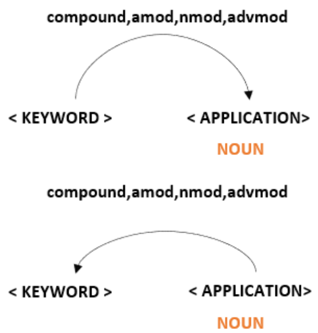
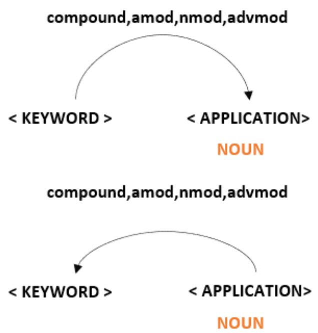
Focusing the analysis on the parameters described in Table 6, it was possible to notice recursive syntactic rules that allowed the extraction of dependency patterns appearing more frequently and aimed at anticipating or supporting, syntactically, the requirements. The features to be considered for the requirements identification were manually searched within a pool of documents.

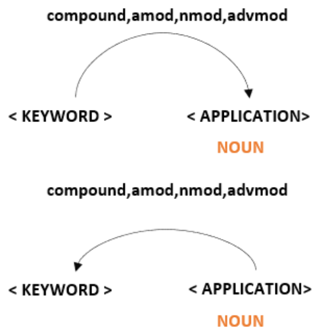
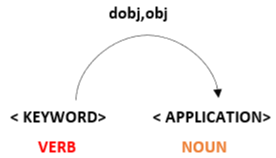
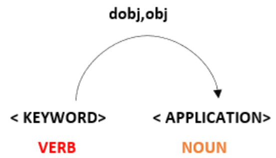
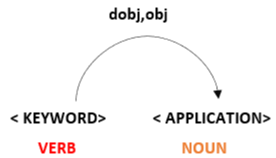
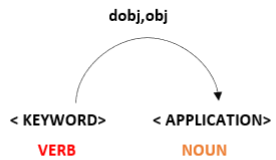
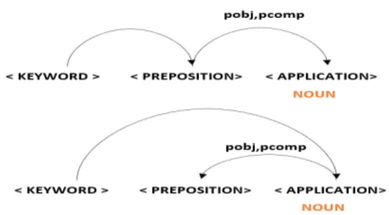
Each requirement could be defined as a technical parameter and an action. In a linguistic point of view this can be seen as a couple of noun plus a general action. In addition, requirements could also appear in association with the linguistic forms -proof, anti-, -less., etc.

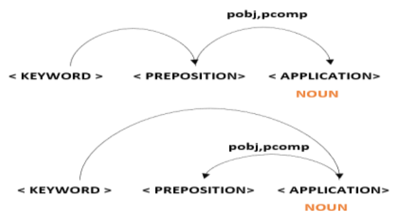
Table 7 provides a schematic representation of the dependency patterns provided for requirements extraction from the text. The patterns shown are only a sample of those semantic relationships which achieved the best outcomes of the several reports that were examined.

Table 7. Dependency patterns list for the identification of Requirements in the sentence of a patent text.

Dependency patterns	Dependency patterns description	Related sentences (examples) from patent text	Dependency parse visualization
-bility	Noun ending with –bility	[…] **enhance flexibility** for positioning the system according to some embodiments US20200085284A1 […]provide laser treatments to **increase the flexibility** of the lens US10667950B2	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>
-friendly	Noun ending with –friendly	**Environmentally-friendly** liquid container US9090372B2 Glove with **hand-friendly** coating CN101410030B	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>
-less	Noun ending with –less	[…] **needle-less** injector to cause an injection into an intramuscular layer US20180361070A1 […] **contact-less** integrated circuit US6809703B2	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>
-free	Noun ending with –free	[…] **grant-free** uplink transmission US10673593B2 A **Toll-Free** Management Platform US10778852B2	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>

Anti-	Noun starting with Anti-	[…] **anti-cancer** agent US20200197518A1 […] the secondary auxiliary **anti-counterfeiting** characteristics information US10265996B2	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>
-proof	Noun ending with –proof	**Leak-proof** bean grinding coffee pot CN105708335B A kind of **abrasion-proof** steel ball cleaning sorter. CN204602689U	< PREFIX-APPLICATION> < APPLICATION-SUFFIX> < PREFIX-APPLICATION-SUFFIX>
… **for instance** Un-…-bility			
Less / fewer + noun	Noun is a technical parameters	[…] **less emission** of wave or radiation exposure CN204602689U	
Less + …-ness	General action + noun finishing with -ness	**Less fresh-ness** preserving agent CN109315483A	

Noun + proof	General action + noun	**Water proof** structure connector FI126627B	
… **for instance** Anti + noun, Ability + noun, Damaged / Defect / Error + noun			
Improve + noun	General action + technical parameter (noun)	**Improve channel utilization** US10879945B2	
Update + noun	General action + technical parameter (noun)	A computer system to **update firmware components** US9213537B2	
Enhance + noun	General action + technical parameter (noun)	[…] **enhance privacy protections** US10796782B2	
Diminish + noun	General action + technical parameter (noun)	[…] **diminishing surface densities** ranging from 1×10 6 /cm 2 to 3.1×10 4 /cm 2 US10533156B2	
Reduction of + noun	General action + preposition + technical	Feedback device for **reduction of foot skin damage** in patients with	

	parameter (noun)	sensory loss. US10390751B2	
Lack of + …-bility	General action + preposition + technical parameter (noun)	**Lack of** operational **flexibility**, compactness and modularity […].ES2691722T3	

In general, even though this approach provides a very extensive list of requirements, the final determination of the most significant requirements for comparison is preferable to be validated by an expert in the field.

Finally, Figure 15 summarises, in the form of an infographic, all the steps presented in Section 4.4 for the identification of the Requirements.

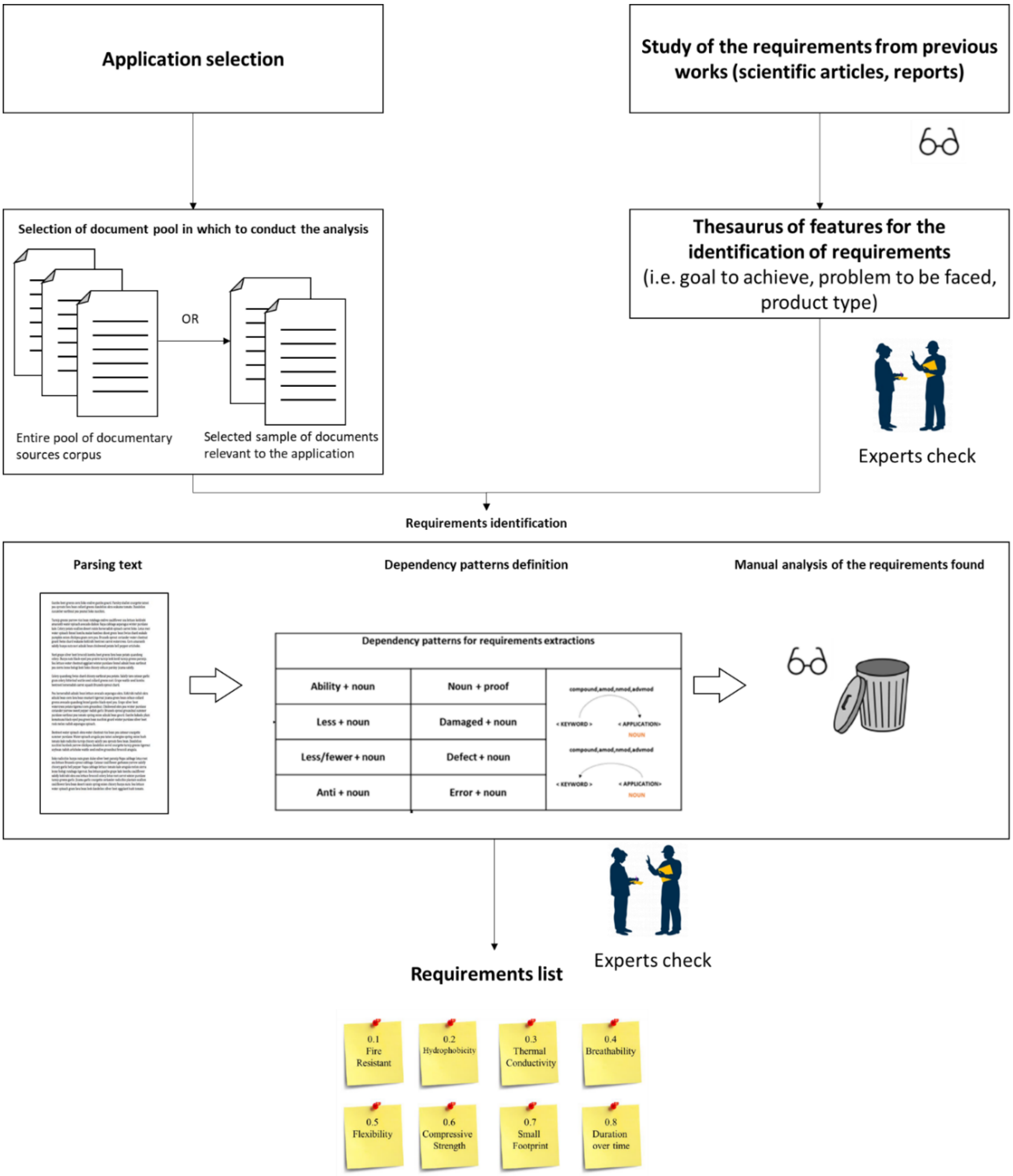


Figure 15. Schematic representation of all the steps taken to identify requirements from the text.

5. Case study: Information retrieval

This Section exemplifies the application of the proposed method with a real case study concerning the use of current-carrying carbon nanotube filaments, woven into the weave of a fabric, which are used to heat by the Joule effect in a uniform and constant manner, with greater efficiency than more common filaments, such as those made of copper.

The initial technological maturity of the product, as measured by the technology readiness level rating scale, is four-five. An initial prototype was tested and achieved the expected and predefined technical results (distribution, heat uniformity, low voltage, safety and wave emission). The aim of the research conducted was to suggest all possible fields of application for the technology, providing a ranking of the most promising from both a technical and an economic point of view.

In the following section, the different steps of the methodology are exemplified according to the case study.

5.1. Collecting the documentary sources and their analysis

5.1.1. Identifying the search keywords in order to formulate queries based on functional logic

Following discussion with the proponent, it emerges that the main objective of the intended product is to heat uniformly and constantly distributed capillary carbon yarns woven into the weave of a fabric.

The product must also be flexible, i.e. able to adapt to a curved or cornered structural configuration, and durable, able to retain its characteristics over time.

Preliminary tests carried out by the proposer prior to the meeting show that carbon yarns transfer heat quickly, have higher electrical conversion efficiency, the yarn structure has high mechanical strength, do not rust, are not subject to corrosion and do not produce electromagnetic fields considered dangerous to human health.

5.1.2. Identify the documentary sources to be analysed

In this case, the collection of documentary sources was carried out using only patents.

The construction of the search query consists of a large set of documents to gather the most of state of the art about the targeted topic: heating fabric. The retrieval query and the results achieved are reported in Table 8. The Orbit Intelligence database was used to construct the patent pool.

Table 8. Retrieval query for the collection of patent pool regarding heating fabric product.

Orbit Intelligence retrieval query formulation	Number of results (Patent families)
(heat+) 1D (fabric+)/TI/AB/TX	16743 results

The retrieval query was launched on Orbit Intelligence. The results of the query consist of 16743 patent families, a collection of patent applications covering the same or similar technical content: heating fabric.

The query is divided into two parts, the first (heat+) 1D (fabric+) contains the keywords heating and fabric to which a truncation operator characterised by the symbol "+" has been applied. In this way, heat+ may corresponds to, i.e. heating, heat, heats and all meaningful words that can be constructed by replacing the truncation operator with letters, numbers or spaces.

To increase the precision of results the search strategy used the proximity operator, i.e. nD, to reduce the distance between terms, where n sets the maximum number of words between keywords.

The second part of the query, on the other hand, indicates the fields of the patent in which to search for the terms present in the first part. In this case in title, abstract and full-text. The priority of the database in searching for keywords starts from the title, if it does not find terms, it proceeds to the abstract and, only at the end, also to the full-text. All documents are automatically translated from the database into English using machine translation.

Below, in the diagram shown in Figure 16, some information and statistics relating to the previously extracted patent pool will be shown. The patents obtained were also analysed manually, extracting a patent sample and verifying that the relevance with the application field is respected.

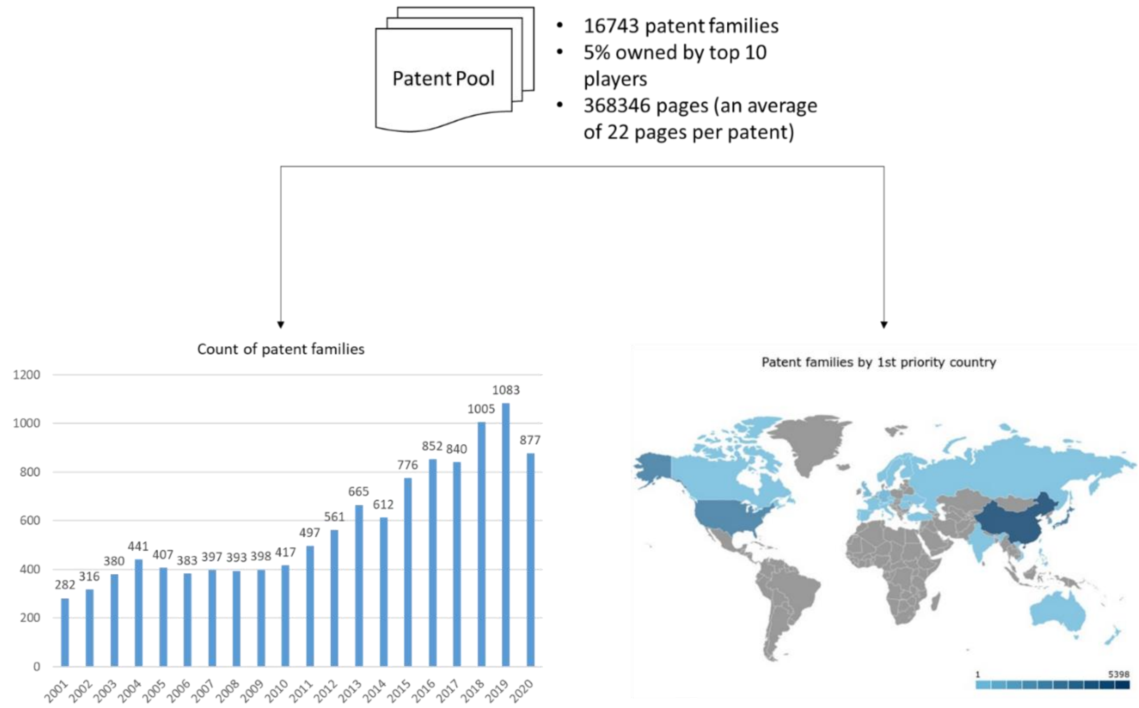


Figure 16. Distribution and geographical market analysis of patents applications in the various national Offices. The information reported is the result of the preliminary processing of the first pool of patents.

The previous graphs illustrate the evolution of applications over time, indicating the dynamics of inventiveness of the portfolio studied (the graphic representation, for aesthetic reasons, shows the results of the last twenty years, sorted by first priority year) and the number of alive patents protected in the various national Offices. This gives initial indications of patenting trends in relation to technology and worldwide patent distribution, identifying in which markets there is most patent activity.

5.1.3. Circumscribe a pool of relevant documents

For each patent belonging to the pool of 16743 patents, the following sections have been extracted:

- Title;
- Abstract;
- Description: outlining the technical field of the patent, state of the art and brief summary of the invention;
- Independent claims: of greater importance since they describe the invention and all and only those elements which enable the invention to be defined in such a way that it appears new and not obvious in the known state of the art;

- Dependent claims: when the claim depends on another and includes all the limitations of the implied claim.

In addition to these sections, priority numbers and dates were also extracted so that the reference of the sentences with the corresponding patent can always be found in the subsequent syntactic processing steps. The extracted files are in .xml or .csv format.

In order to explain the process of extracting information from the patent database, the size of the extracted files and the length of the textual fields to be processed by the Natural language processing software, the extraction procedure for a random patent belonging to the previously identified pool is shown below as an example.

This procedure is summarised in Table 9. The patent that will be taken as a reference and studied is the American extension of the patent family entitled “Activated carbon fibre sheet for automotive canister” and priority number US20210198111 A1.

Table 9. Detailed analysis of patent fields according to number of pages, number of characters of the section to be extracted for the patent titled “Activated carbon fibre sheet for automotive canister”.

	Number of pages	**Number of sentences**	**Number of words**	**Number of characters (space included)**
Title	1	1	8	55
Abstract	1	5	105	573
Description	17	420	8636	54009
Independent Claims	1	4	57	318
Dependent Claims	1	24	316	1899

5.2. Identifying the Functions

Starting from the collection of documents extracted in the previous step, semantics has been used to parse the full-text of 16743 patent documents. A list of technical functions is automatically extracted without the user being an expert of the heating fabric domain. Each sentence was automatically analyzed through spaCy software, according to the modalities explained in Section 4.1.

Then the results of the syntactic analysis provided by the software were compared with the syntactic structures of the proposed dependency patterns to evaluate their adherence. In this case, the elements of the sentence were associated with the ontological roles specified by the dependency patterns to extract and catalogue the information contained therein.

The first list of Functions was extracted by searching "heating fabric" or only "fabric" as subject of a triad containing verb and direct objects (both in active or passive sentences).

Considering, for instance, the sentence: "heating fabrics use to melt snow" [Patent number: US20170027024]. SpaCy parser is used as dependency semantic parser (Figure 17).

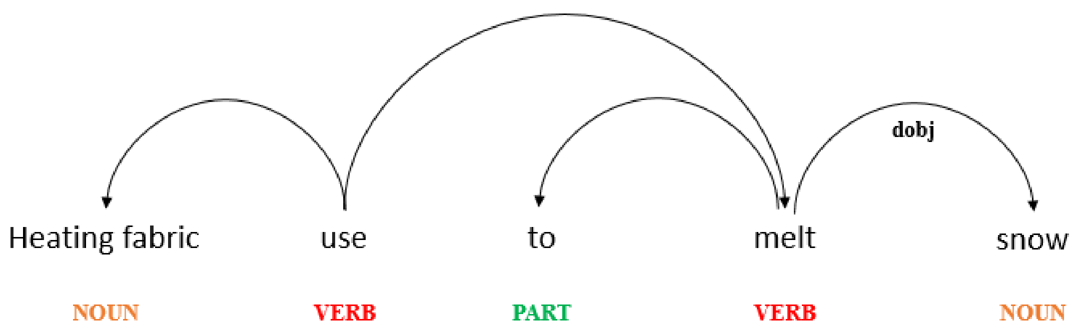


Figure 17. Example of sentence analysis using a dependency pattern. The sentence is taken form patent priority number US20170027024.

In Figure 17, defined using a dependency visualizer, it is possible to observe semantic relationships connection (to+verb), the subject (heating fabric) and the function (melt). The novelty of the research, pertaining the Information retrieval phase and the extraction of the Functions, lies in the extension of the search not only to SAO triads but also to other semantic relationships to be searched in combination with a dependency parser. Each one of them was chosen only if there was at least one relationship with heating fabric within the same sentence, in order to increase the probability that the function + object was referable to the given technology.

The following table (Table 10) shows a partial list of some Functions that it was possible to extract through the analysis with the dependency patterns. To give evidence of the patterns used for their extraction, for each Function we report the sentence within the patent through which it was possible to extract the Function. For the sake of brevity, only results extracted by applying Sao, To, For and can relations were considered.

Table 10. Partial list of Functions obtained by applying SAO and other semantically dependency patters according to a Natural language processing software implementation.

Functions	SAO Triads	To + action	For + action	Can + action
Melt		Use to melt snow US20170027024		
Keep dust away	It avoids any mixing of dust WO2019/092370			
Heating to change object shape	The heating fabric changes the form CN107587234	Heating the fabric to restore the volume WO2015/056543		
Control heat conduction	Control heat conduction input GB849163A	Fabric to control heating conduction US6723967B2		Heating fabric can still conduct heat CN209250908
Dry		To heat drying apparatus WO2020/015278	Heating for drying an adhesive KR2003007595	the heating effect […] and can effectively relieve dry eye symptoms. CN108201479
Heating	Heating the outgoing air jet RU136462	To wrap and pre-heat the tires CN105706525		The uniformity of heat can be improved EP1916898
Thermal Insulation		To insulate (thermically) in advance CN105088600		Can be freely formed to perform heating thermal insulation CA2673501

Increase Comfort	Heat generation increase the comfort of the garment CN109348553		For increasing the comfort level US20190315372	
IR Emission	Heating fabric powers an anion and far infrared rays KR20120004099	To cut IR emission. DE202009003858		
Burning	To burn off any remaining coating. TW201024488			
Store Energy			For storing the energy. KR2013003919	
Ion Emission				Oxygen ions can be released through. EP1831449B1
Electronic Shield				Can be selected to provide electronic shields. CN103194842
Light Absorption				Heating fabric could absorb the light. EP2404973A1
Avoid Electrical Shock				Could avoid electrical shock. US20090032524

In addition, a summary diagram is reported below in Figure 18 showing all the functions presented in Table 10, subdivided according to the dependency patterns used for their extraction. The representation of the Functions is realised through an infographic that subdivides the Functions identified through SAO: e.g. Melt to attach, keep dust away, heat to change object shape, heating for drying, comfort, IR emission; Direct proposition to: e.g. melt to attach, heat to change object shape, control heat conduction, heating for drying, heat, thermal insulation, IR emission, burn; Direct proposition can: e.g. control heat conduction, heating for drying, heat, thermal conduction, comfort, ions emissions, electromagnetic shield, light absorption, avoid electromagnetic shocks; direct proposition for: heating for drying, comfort, store energy.

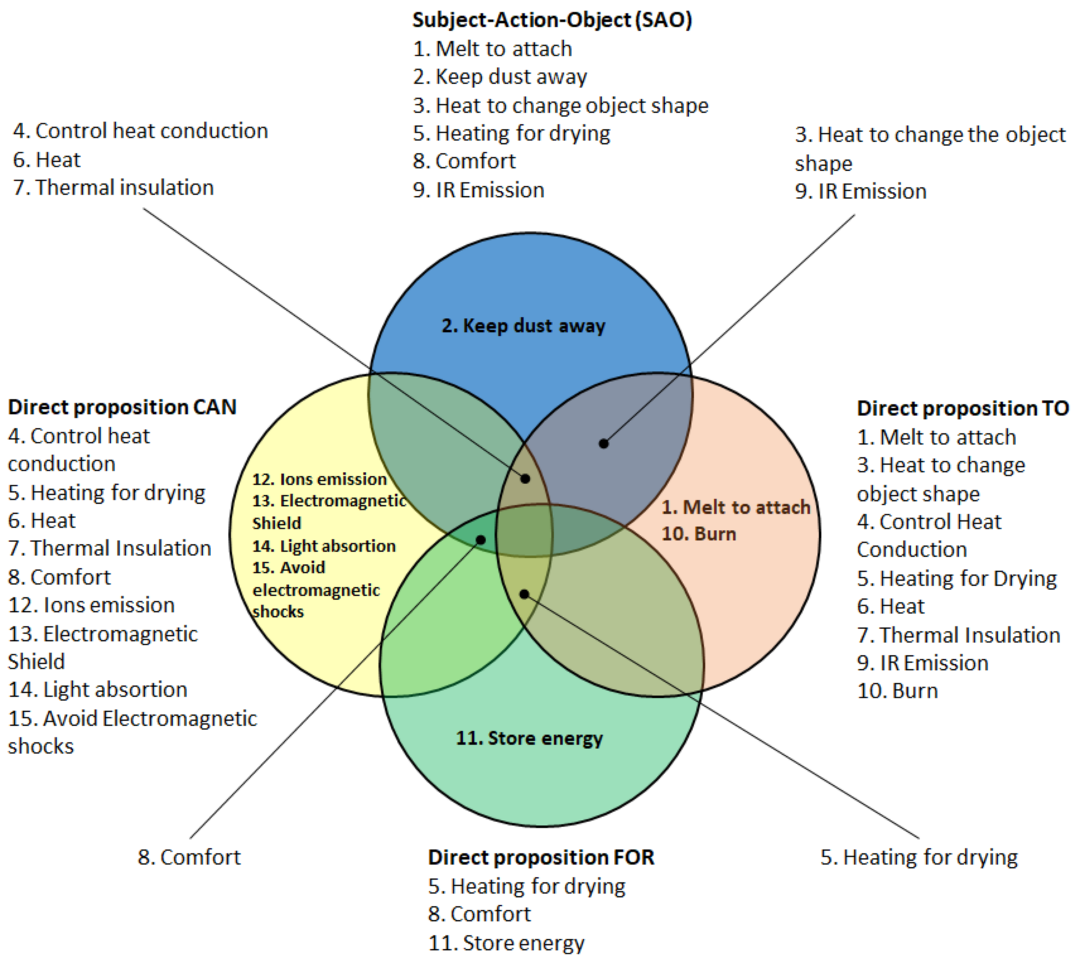


Figure 18. Graphical representation of the list of functions related to heating fabric according to SAO technique and other novel semantic relations.

Each sentence extracted using SAO triads and dependency patterns was manually checked to ensure that the extracted Function was correct from an ontological point of view. All the verbs that are not (1) pertinent to the product under investigation, (2) pertinent to the technology transfer objective, (3) the transformation of the Object into the Product is not evident, were manually discarded.

Most of the extracted verbs refer to actions aimed at producing or modifying the tissue. These verbs are not Functions and therefore discarded following manual analysis. The list of verbs that make up the Functions refer to those actions that the fabric is able to produce on a third object and on which the enabling technology (heating) has a direct relevance.

In a more specific way, the investigation relates to how the heating fabric can dry, melt or produce IR radiation on another object thanks to its heating power. Simultaneously, Functions related to the actions of e.g. wrapping, compacting, welding, folding are not relevant for the analysis and then excluded. This verbs identify the product as such and not for the purposes for which it has been designed. This phase has been carried out entirely manually.

In addition, with the aim of evaluating the usefulness of the work done in the search for dependency patterns, a further test considered a validation of the method with the aim of evaluating the recall index between the dependency patterns introduced in this work and the SAO triads. For this analysis, a sample of 1000 documents containing the words "heating fabric"

In title and abstract have been considered and the analysis of extraction of Functions have been repeated. The results showed that compared to functional verbs the SAO triads has a rather limited recall index, covering barely 37% of all significant verbs. It was therefore necessary to integrate the SAO technique with a set of rules based on other semantic relationships.

Figure 19 reports the results of the recall analysis considering the comparison among the identificaiton of Functions conducted with SAO and the other dependency patterns. The dependency patterns presented are only those for which the highest recall values were recorded. The evaluation was carried out considering all dependency patterns. Finally, the pie chart shows the percentage distribution of the results obtained.

Dependency parse relations	Recall
SAO	37%
TO	44%
FOR	21%
CAN (indirect)	58%
AS	9%
BY	27%
OF	16%
USED FOR (indirect)	10%
USED TO (indirect)	14%
Others	...

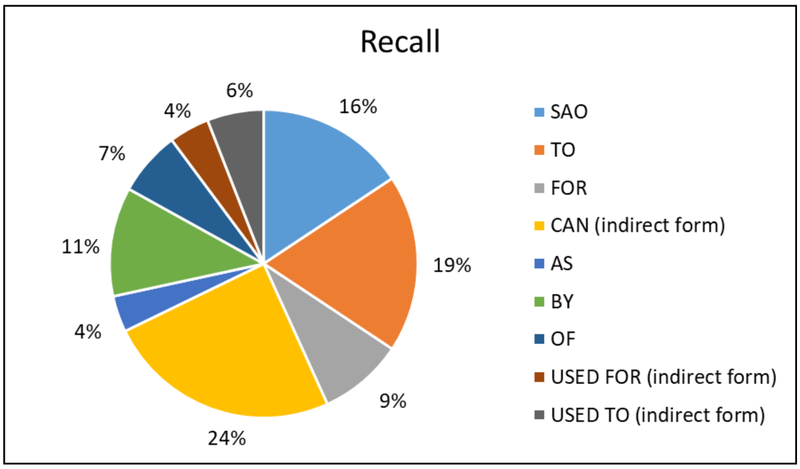


Figure 19. Recall index calculated considering SAO technique vs other semantic relations on a sample of 1000 documents analysis. Recall is calculated only on functional verbs.

5.3. Identifying the applications

The starting point for the extraction of application fields is based on the entire patent pool and the Functions extracted in the previous step. Each of the Functions will allow the extraction of a list of application fields by means of SAO triads and dependency patterns.

Before presenting the procedure followed for application extraction, it is necessary to make a distinction regarding the results that can be obtained from this analysis. This preliminary activity varies from case study to case study and is a point to be discarded depending on the needs of the researcher or entrepreneur, possibly to be provided as auxiliary research by the service offered by the TTO. If the target of the research is to provide a list of applications all related to the given technology, the number of results obtained might be very high and dependent on the degree of development of the technology.

With regard to heating fabric, therefore understand what possible applications a carbon fibre heating fabric can have. In this case, the extraction of applications from patent pools does not require sector-specific expertise. Table 11 gives an example of the dependency patterns used to extract applications from Functions. The table shows only a partial list of results and aims to show the dynamics of operation and integration of dependency patterns.

Table 11. Partial list of applications automatically extracted by combining the function and a predefined set of semantic relations. The examples show the matching text and the patent document number

Dependency patterns	F	Application	Phrase	Patent ID
such as	Heating	Floor covering surface	Abstract. […] placing a sheet of flooring in a heating fabric textile by laying a snow-melting pavement sheet wound in a roll shape on a road surface such as a floor covering surface	JP04115001
as well as		Mat	Abstract. Snow melting surface as well as heating fabric mat for stairs	JP2000328509
used for		Pad	Abstract. A rubberized heating pad applied used for melting snow on roads	US20160369466
used to		Panel	Abstract. A rubberized heating fabric panel composite, used to melt snow and used to dissipate cold draft	US20170027024
used as		Thermal pad	Abstract. The present invention comprises a carbon fibre heating fabric used as a desktop thermal pad	KR200471655
used for		Shoe-pad, shoes	Abstract. Carbon fibre heating used for shoes or shoe-pad	JP3186052
to obtain		Floor heating device	Abstract. To obtain a floor heating device	CN205082764
such as		Mat	Abstract. […] placing a sheet of flooring in a heating fabric textile by laying a snow-melting pavement sheet wound in a roll shape on a road surface such as a floor covering surface	KR20120004099
to		Blanket, garment	Abstract. Snow melting surface as well as heating fabric mat for stairs	CN202109574
as		Seat of motor vehicle	Abstract. A rubberized heating pad applied used for melting snow on roads	DE102006038612
as well as		jacket	Abstract. A rubberized heating fabric panel composite, used to melt snow and used to dissipate cold draft	TW201024489
used as	Dryin	Underpants	Abstract: The utility model discloses a [..] postoperative protection used as underwear or	CN207721226

			underpants, including the pants body, protection casing and a heating fabric device […]	
used for		Textile material web	Abstract: […] the dryer used for textile material web and […] with the heating fabric device […].	EP2694900
as well as		Tea stir-drier	Claim 3: dry leaves mechanism as well as tea stir-drying machine […] in the proximity of the heating fabric textile	CN102652521
and		Tea stir-frying	Abstract: The invention discloses a tea stir-frying and drying device […] for a textile material heating fabric […].	CN108036612
used for		Tobacco chamber	Abstract: The utility model discloses a [..] postoperative protection used for underwear or underpants, including the pants body, protection casing and a heating fabric device […]	CN107411165
such as	Melting	Floor covering surface	Abstract. […] by laying a snow-melting pavement sheet wound in a roll shape on a road surface such as a floor covering surface […] constituted by a heating fabric device.	JP04115001
as well as		Mat	Claim 1: […] containing a flexible heating fabric sheet [..] the snow melting surface as well as mat for stairs	JP2000328509
used for		Pad	Abstract. heating fabric pad applied used for melting snow on roads	US20160369466
used to		Panel	Abstract. A rubberized heating fabric panel composite, used to melt snow and used to dissipate cold draft	US20170027024

In this manner, from the starting pool of 16743 patents, ninety-six applications employing carbon fibre heating fabric technology were extracted. All ninety-six applications were checked manually by reading the sentence from the source document and doublechecking with the content of the patent text. This ensures that the applications found employ the technology.

The list of applications found is provided in Table 12. In order to make the results more readable, a classification was made in order to group similar technological applications by application field and the Functions that were used to identify and extract them.

Table 12. Partial list of potential applications for a carbon fibre technology based on heating fabric technology.

Application field	**List of applications**	**Functions**
Medical	Health waistband	Control heat conduction
	Health belt	Heating for drying
	Health shoe	Heat
	Wheelchair	Thermal insulation
	Blood circulation garment	
	Eye bandage	
	Insoles	
	Foot soles	
	Physioteraphy underpants	
	Neck cushion	
	Scarf	
Protective devices	Fan blades	Melt
	Deicing	Control heat conduction
	Fan blade deicing	Heat
	Wind turbines blade deicing	Thermal insulation
	Emergency house room	
	Underground cable coating	
	Pre-heat of tires	
	Heated tank	
	Heated gas	
	Storage	
	Autoclave	
	Anti-flame coating	
	Insulate panel (water repellent)	
Industry / building	Electric patinting	Melt
	Decorative paper	Control heat conduction

	Wall radiator	Heating for drying
	Tea stir drier	Heat thermal insulation
	Tobacco chamber	
	Adhesive plaster	
	IR Greenhouse	
	Covering floor	
	Boiler	
	Kettle	
	Blind window	
	Battery protection	
	Airbag protection	
	Heating pipeline	
	Wallboard	
	Underfloor	
Comfort	Pot	Control heat conduction
	Roaster (rice, coffee)	Heating for drying
	Smokeless oven	Heat
	Neck cushion	Thermal insulation
	Pants	
	Pocket pants	
	Dry cloth	
	Solar bed	
	Toilet seat	
	Sofa	
	Garment	
	Gloves	
	Cap	
	Socks	
	Camera tripode joint	
	Blanket	
	Cushion	
	Curtain	
	Sleep bagging	
Transport	Snow prevention (airplane, train, railways, roads)	Melt Control heat conduction

	Deicing (avio, navy)	Heating for drying
	Heating asphalt	Heat
	Roads	Thermal insulation
	Emergency heating track	
	Truck sleep chamber	
	Vehicle shoe	
	Pedal	
	Bicycle heating frame	
	Auto’s doors	
	Auto / moto windshield	
	Seat (vehicle, moto, bicycle)	
	Auto’s doors	
	Auto, moto windshield	

All applications found in Table 12 employ carbon fibre heating fabric technology. The classification used was defined by the candidate after identifying the overall list of applications. Each application is the finding of one or more patents. The phrases from which it was possible to extract them are part of the title, abstract and claims. The extracted phrases in the description may refer to the state of the art and, therefore, there is no certainty that these phrases refer to the application that is useful to extract in this search and that employs the given technology.

The medical classification refers to applications whose intended use is for the diagnosis, cure, alleviation and treatment or prevention of a disease. Otherwise, they affect the structure or a function of the human body. This distinction can also be made by reading the cooperative patent classification of the corresponding patent.

The versatility of the technology also finds applications in the field of protective devices: for instance, in the automotive field aimed at improving the performance of some components sensitive to rigid temperature changes, such as racing tires, or applications inside devices to counteract the presence of snow both in the construction field and in transport vehicles.

In Figure 20, some examples of the product application fields are shown. The images shown refer to the drawings of some patents that were used to conduct the analysis and identified using dependency patterns. In particular, the first draw on the left concerns a carbon heating fabric heating clothes extracted from patent number: KR10-2005-0053144 A. On the top-right, a heating seat application for a vehicle using a carbon fibre heating fabric from the patent number: KR20-1254154. On the bottom-left, a home greenhouse application using carbon fabric heating element and intelligent control algorithm from the patent number KR10-2019-0076857 A.

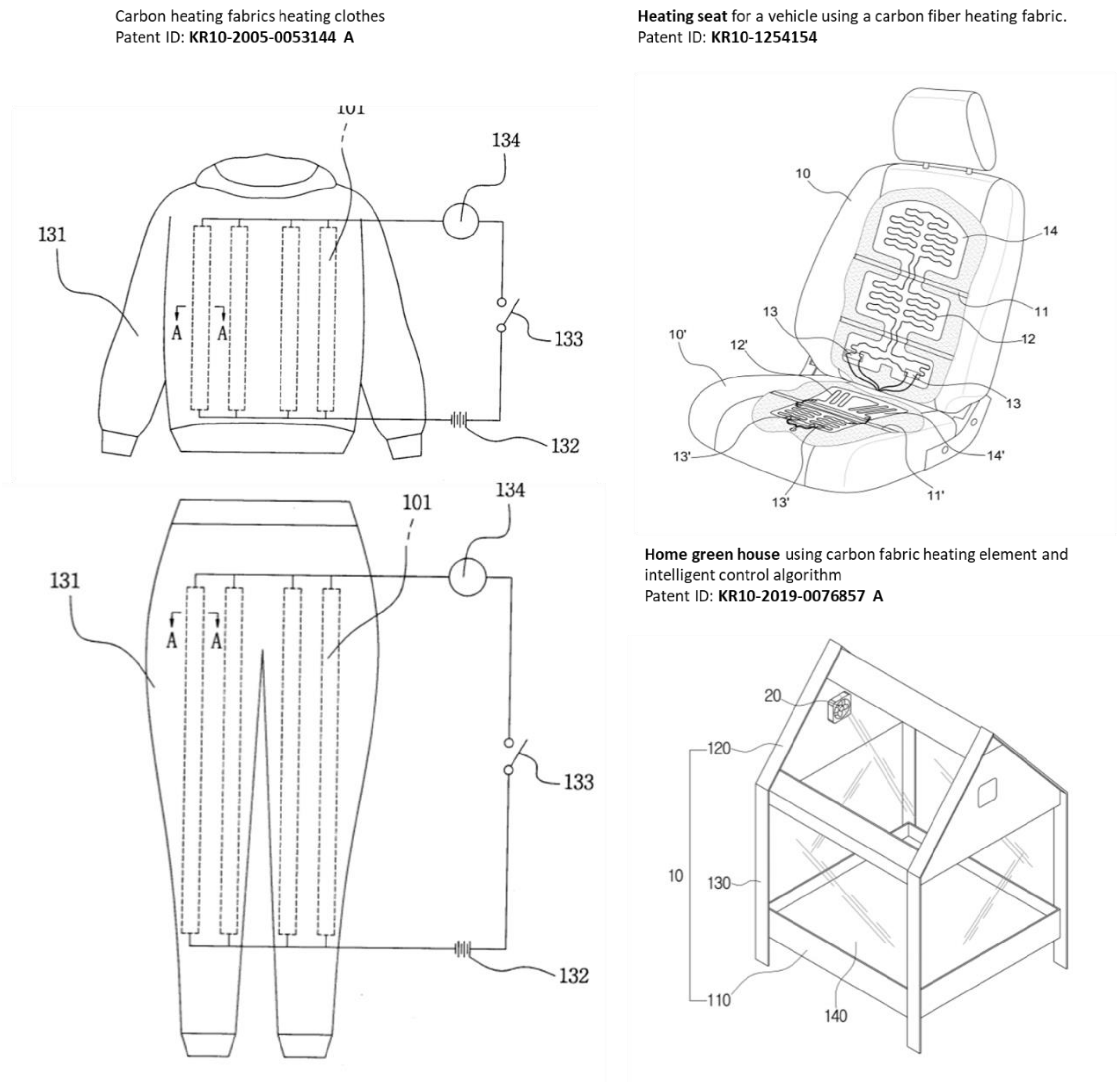


Figure 20. Examples of application fields for the heating fabric product. The drawings are taken from the patents and relate to three applications: carbon fabric heating clothes: sweatshirt and pants; heating seat and a greenhouse using carbon fabric heating elements.

Starting from the applications identified, there are already a large number of state of the art applications for heating fabrics that mainly use copper electric coils. The replacement of such technologies with carbon fibre-based technologies could in many cases be a natural evolution towards a new S-curve.

5.4. Identifying the requirements

For each of the previously identified applications, a literature searches to identify the number of relevant patents was carried out. In this way, by collecting the pertinent patents, it is possible to identify all alternative technologies that allow for the realisation of that particular application, always within the perimeter circumscribed by heating fabric.

The results were shown and documented to the company contact person. Based on the comparison, some applications were identified that could transfer the technology and be developed within the textile company. The applications that were considered for analysis are the following: heating mats, heating insoles and heating mattress. In this thesis, the heating mats application will be shown as an example.

Heating mat can be used externally or internally in a house. This application allows a versatility of uses in the domestic environment, which can be used, for instance, to offer thermal comfort to pets.

A bibliographic search was carried out to identify the number of relevant patents and, by means of a web search, all the scientific catalogues of the companies producing the application identified. This manual screening identifies and takes into account two comparing technologies: copper and carbon.

Table 13 presents the collection of patents and the retrieval query. The analysis was conducted on Orbit Patent Intelligence database searching on full-text of English patents and on the web considering 877 patent families. From this collection, copper wire and carbon fibre technologies were identified. Both copper wire and carbon fibre are sold in the market and patented.

Table 13. Example of information extracted from documentary sources for the 'heating fabric' case.

Collection topic	**No. Doc.**
Heating mats *Search query: (heat+) 1D (fabric+) AND (mat?)/TI/AB/TX*	877
Heating mats by copper wire	129
Heating mats by carbon fibre	748

Table 14 presents the list of the requirements extracted starting from the pool of selected documents regarding heating mats and processed through the Natural language processing tool. Each requirement is extracted starting from the list of dependency patterns identified for requirement's identification. All of the results were manually checked by experts in the field.

Table 14. List of requirements identified for "heating mat" application, its description and the corresponding numerosity of patents.

Requirements of Heating Mats	**Description of the requirement**	**No. Patents**
Increase flexibility	The ability of the material to bend or to be bent easily without breaking	529
Reduce thickness	Measure of cable diameter	503
Easy replacement	Ability to replace material easily and without high costs	477
Average temperature	Ability to maintain temperatures in a predetermined range	331
Corrosion resistance	Capacity of the material to slow and continuous consumption of a material	291
Ergonomic	Reducing human body fatigue and discomfort	221
Heat uniformity	Consistency of heat over time	207
Low voltage	In electric power transmission and distribution, low voltage values allow relatively low currents (compared to very low voltage) and greater safety (compared to medium and high voltage where there is a risk of arcing).	117
Reduce weight	Reduce weight	115

Cable dimension	Measure of cables length	109
Temperature/heat precision	The ability of a measurement to be consistently reproduced	103
Heat dissipation	Heat dissipation occurs when an object that is hotter than other objects is placed in an environment where the heat of the hotter object is transferred to the colder objects and the surrounding environment.	101
Thermal inertia	The ability of a material or structure to vary its temperature slowly in response to external temperature variations or an internal heating/cooling source.	100
Wave emission (medical)	Electromagnetic radiation exposure of human body	97

6. Proposal: Business evaluation

With the identification of the requirements, the Information retrieval part of the method can be considered concluded. In the following sections, the proposed method is used to evaluate the most strategic applications field, among those identified.

Starting with the applications extracted semi-automatically from the text, the method aims to identify and rank the convenience of a technological substitutions by processing documentary sources. The identification of potential applications that could benefit from the given product is carried out separately for each of the requirements that best represents them.

To perform the ranking of the applications identified, a novelty analytical tool called technology substitution graph is proposed. This tool is based on two dimensions: a technical perspective (Transfer potential) to measure the potential of technology substitution evaluation based on market potential and an economic perspective based on economic trend evolution over time defined as the Earnings Before Interest and Taxes (EBIT) and patent costs for a determined period of time.

In this Section, the method proposed by the candidate to address the open problems concerning Business evaluation identified by the literature (Section 2.1) and the operational context (Section 3) is introduced and explained.

In extreme synthesis, the method concerning Business evaluation (Spreafico and Russo, 2021) consists of three main steps in order to evaluate the most strategic application fields, among those identified during the Information retrieval phase (See Section 4), on the basis of technical product requirements and economic criteria.

The first step (Step 1.1, see Section 6.1) concern the evaluation of product requirements on the basis of their commercial appeal. (Step 1.2, see Section 6.2) Estimate a potential economic value of the product based on the cost of patenting similar patents and the income of companies commercialising similar products. (Step 1.3, See Section 6.3) Comparing Market and Economic potential.

Figure 21 schematically presents all the steps and sub-steps of the proposed method.

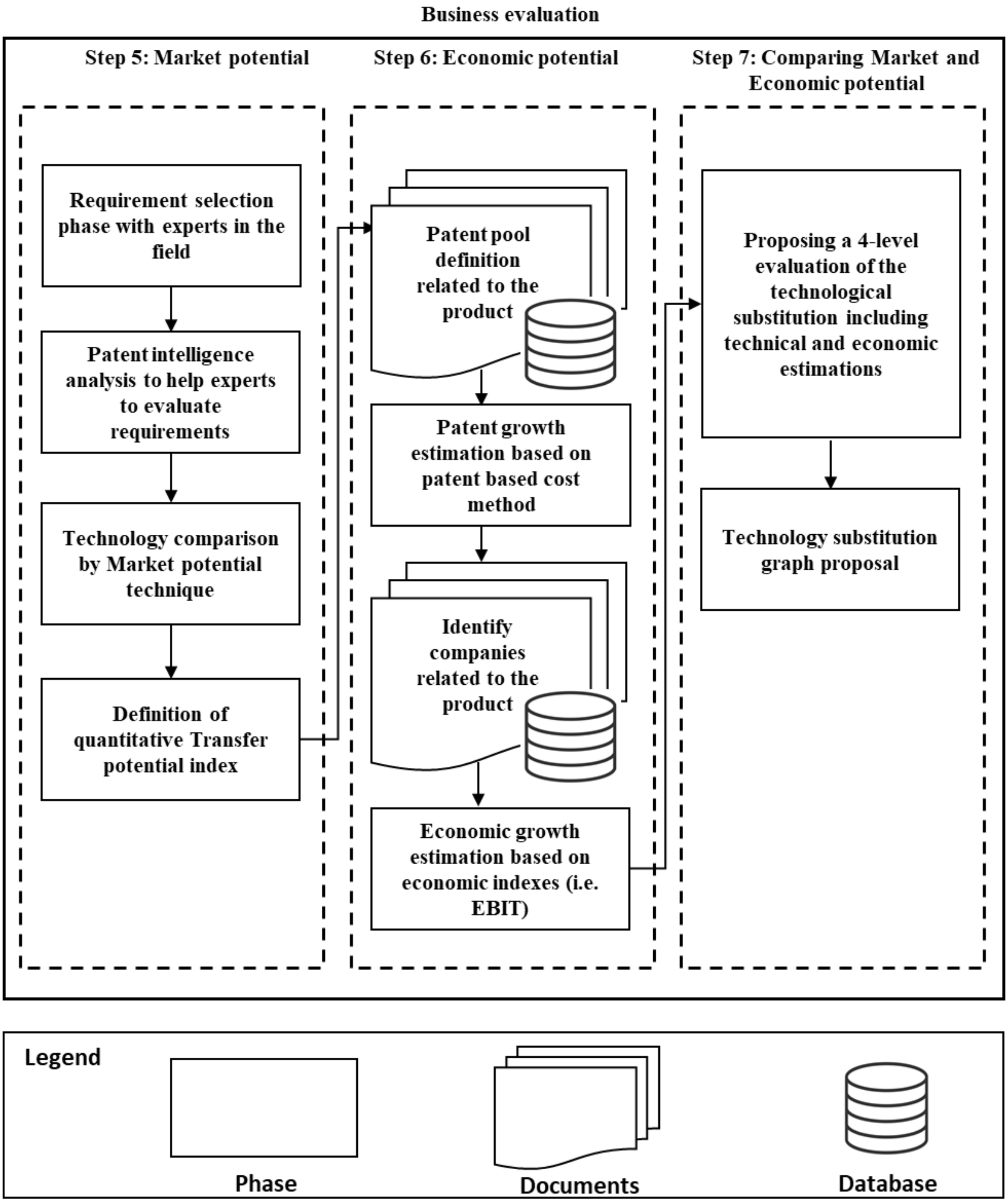


Figure 21. Overview of the suggested method.

6.1. Market potential

The study presented in the dissertation is addressing various needs for both academia and industry with the aim of supporting technology transfer regarding the definition of innovations tasks in the very early stage of the innovation process.

In this regard, in order to structure a process to support innovative ideas based on new fields of application of an emerging technology, it is necessary to identify the products to be invested in, to be valorised by bringing them to the market through technology transfer actions such as licensing and/or creation of spin-offs or to bring them to the attention of possible investors.

To do this, supporting approaches for comparing technologies must be applied. Developing a technology transfer method requires not only the identification of potential new fields of application, but also a method to measure the potential replacement of the new technology compared to those already on the market, comparing the different results obtained in the research phase and suggesting the best investment to make.

The choice of the most suitable approach for comparing technologies is based on many factors. These can be summarised as: degree of technological maturity of the product, the structure of the market, competition and the identification of remaining areas not yet covered by marketing and/or patents.

Of several approaches used for assessing market potential, one technique consists of assessing a set of customer needs and requirements, with a structured procedure to convert them into technical parameters and a strategy to manufacture products that essentially meet those needs.

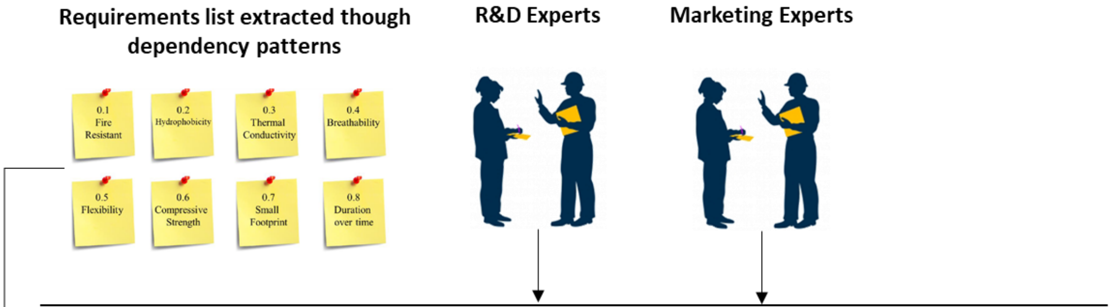
Benchmarking is one of the earliest form of structured product development. Products are compared with industry bests from other companies and improvements are planned to cover possible gaps or to overcome competitor's performances. In particular, satisfaction is a measure of how products and services supplied by a company meet or surpass customer expectation. In a scale from 0% to 100%, 0% is the absence of the feature or great dissatisfaction, 100% is maximum satisfaction.

The supporting approach used to carry out the analysis is the market potential technique, introduced by Ulwick (2002) and then resumed by Russo et al. (2019).

In the event that the case study to be addressed concerns the study of an application field of a product that can be carried out using different technologies, the market potential analysis must be performed for each technology under investigation, by comparing the one to be transferred with each alternative.

In regards to the final evaluation, however, it will have to be carried out involving experts in the field and it will remain subjective. The method proposed in this dissertation, though, enhances the market potential technique by proposing the use of natural processing tools for the extraction of the requirements list and for each one of them, counting how many patents contain information to make the evaluation more consistent in quantitative terms.

Figure 22 reports the method followed for the evaluation of the requirements identified and the consequently representation in a graph of the market potential values evaluated for each product.



Requirements	Importance %	Satisfaction %	Market Potential
Reduce Energy	30	100	6
Reduce Cost	30	100	6
Reduce Dimension	90	80	20
Improve Safety	0	100	0
Improve Controllability	90	80	20
Reduce Weight	80	80	0
Reduce Envirnomental Impact	90	80	20
...	...	...	...

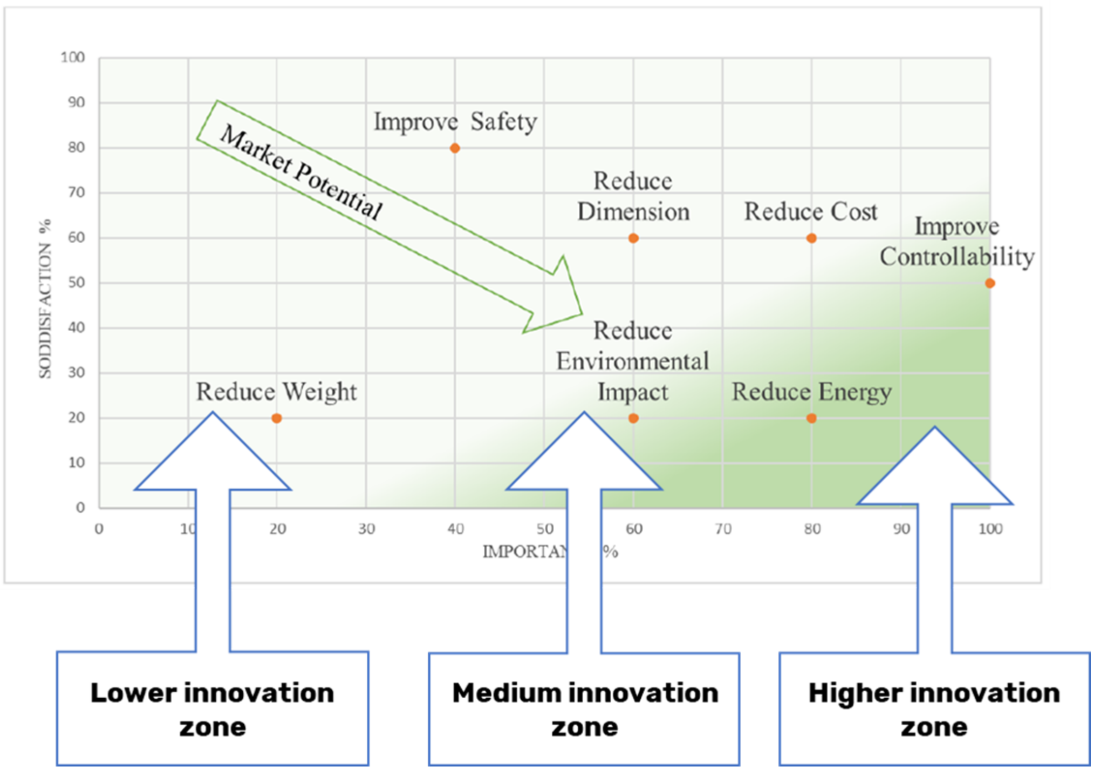


Figure 22. Overview of the methodology for requirements evaluation with market potential technique.

As shown in Figure 22, requirements extracted by semantics and manually checked by experts are the starting point of the market potential technique, as comparison factors for product evaluation.

The evaluation of each product according to Importance and Satisfaction provides a unique value that can be used as an indicator for the overall assessment of market potential. From the value obtained, it is possible to determine its positioning within a matrix graph that makes it possible to determine whether or not the product belongs to an innovative area for which it is advisable to carry out technology substitution. The evaluation phase of Importance and Satisfaction is carried out by experts in R&D for the former and in marketing for the latter.

The assessment of requirements will in all cases be subjective. In order to support the evaluation made by product experts (R&D Team and Marketing Team), a search for knowledge must be carried out. This involves, for example, the research in each requirement for information contained in brochures, commercial catalogues, patents literature and scientific articles with the aim of extracting trends, statistics, emerging technologies and un-resolved problems.

This information has to be relevant to the various requirements and is intended to provide additional supporting and useful information to the experts carrying out the assessments of the value of the importance. The objective is to build a dashboard (infographic) containing information in the form of graphs and tables extracted and processed from selected data extracted from patents, brochures / trade catalogues and scientific papers. The graphs are generated based on specifically created pools of requirements based on some common characteristics, listed below and explained:

- Patent density/numerosity: graphical representation of the number of applications patents filed over the years, globally.
- Key applicants active in the market: information on the leading applicants active in the market by number of patents filed for a given period of time.
- Legal status: the number of patents alive, dead or abandoned.
- Investment trend: evolution of patent applications over time, indicating the dynamics of inventiveness of the portfolio studied.
- Geographical distribution of patents: geographical distribution of patents sorted by patent families showing active coverage and reference time period. This graphical representation provides useful information for understanding the

investment strategy of the applicants active in the market and the level of inventiveness.

The graphical dashboard is intended to accompany the evaluation phase, with the aim of providing evaluators with useful and up-to-date information to help them formulate their criteria.

Figure 23 shows, as an example, a dashboard encompassing all the previous graphical representations, divided by bibliographic data (e.g. time distribution of patent applications over time, legal status), technology landscaping (e.g. technology mapping), geographical distribution (e.g. distribution of competitors), application landscape (e.g. graphical representation of classification codes), comparison of competitors (e.g. comparison of patents by time and graphical distribution, national vs. competitor distribution), application landscaping (e.g. graphical representation of classification codes), competitor comparison (e.g. comparison of patents by time and graphical distribution, national versus international patent applications over time) and, finally, some claim considerations.

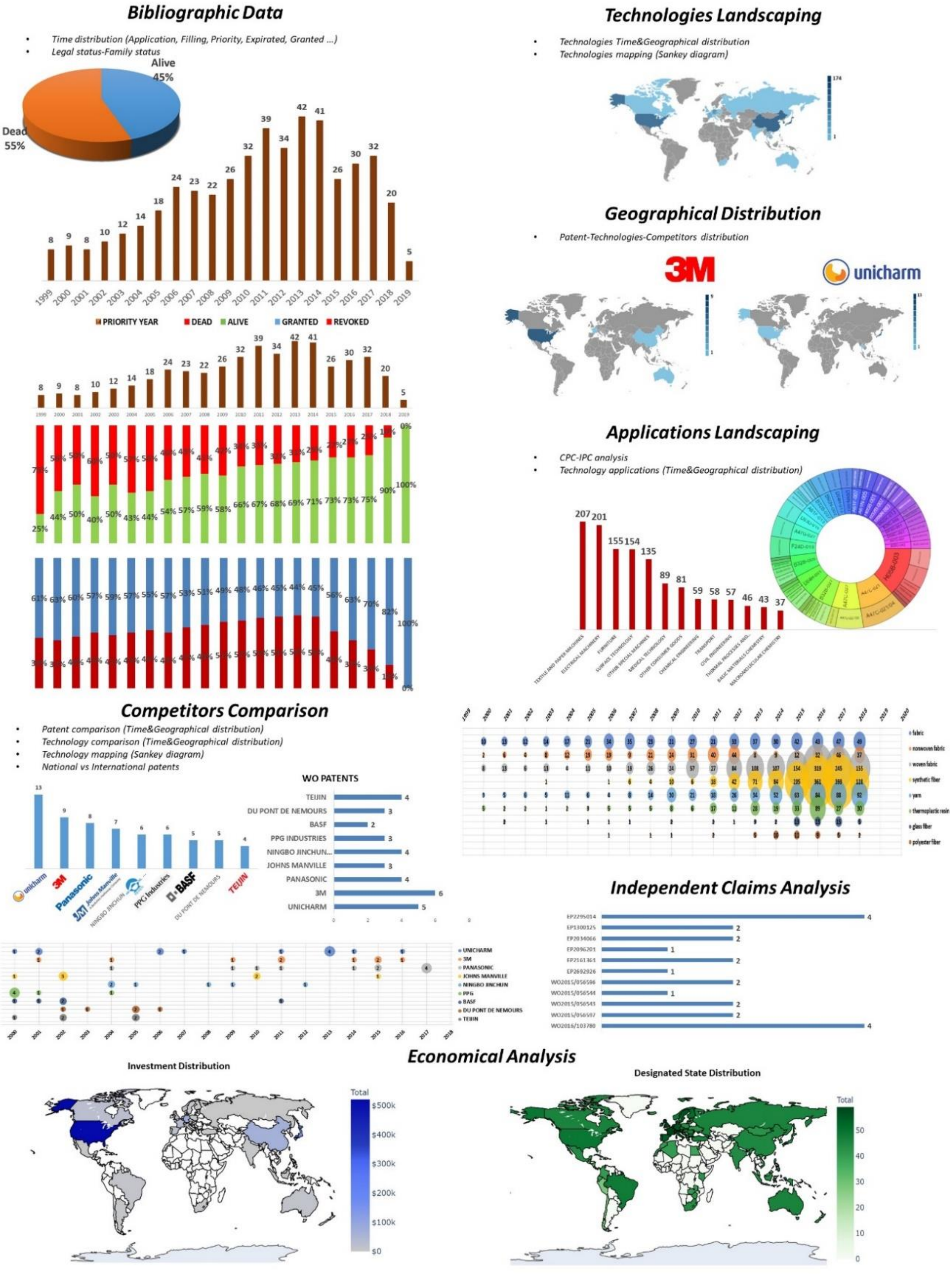


Figure 23. Dashboard creation to support experts for the assessment of requirements.

In order to assess the technical feasibility of replacing a product with a new technology, it is advisable to identify the main technologies for a given product from the documentary sources that make up the state of the art, and to compare them in terms of technical performance.

Finally, in Figure 24, a schematic representation of the steps followed for the definition of market potential alongside with technological comparison and patent intelligence for the suggestion of graphs and statistics that helps the phase of requirements evaluation by experts in the field is provided.

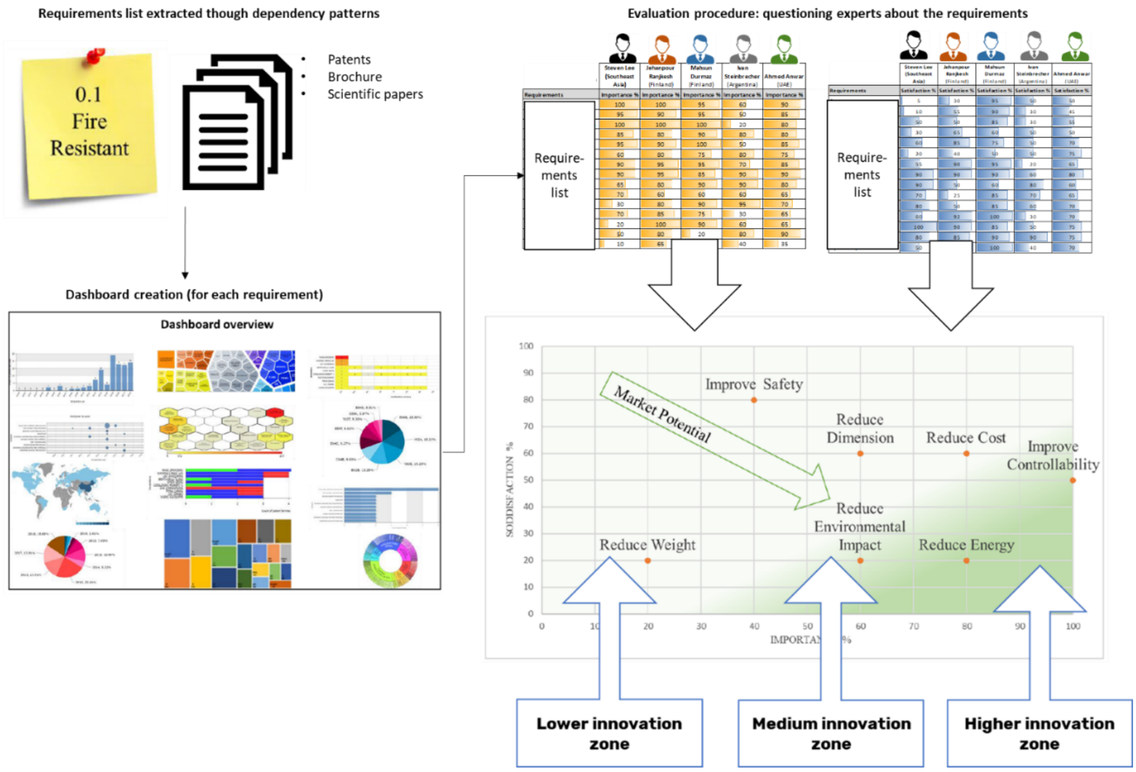


Figure 24. Schematic representation of all the steps taken to evaluate the market potential analysis of a product.

6.2. Economic potential

To assess the most strategic fields of application, in addition to evaluating the technical requirements of the product on the basis of their commercial appeal using the market potential technique, the proposed method suggests economic criteria.

In the case of the assessment of technical product requirements based on their commercial appeal (Section 4.4), the general objective is to have a greater satisfaction for each requirement, preferably for the highest innovation potential. In this case, one or more innovation strategies have been proposed to the researcher and the other persons that were responsible for investments.

However, the previously reported approaches based on market potential and optimised for the comparative comparison of products to perform technology transfer through semantics and text analysis, offer only a first step to estimate the risk to invest through a comparison of the ability to penetrate the new market of competing technologies.

The integration of the method relating to the estimate of the market potential of a product is to offer a complementary analysis to the study carried out with the market potential, which offers the researcher and / or the entrepreneur information of an economic nature in support of the technical convenience.

The estimation of the Economic potential is based on two sub-steps: the first one concerns the calculation of the patent cost and, the second sub-step is based on the calculation of the company's result before taxes and financial charges, based on data provided by the financial statements.

6.2.1. Patent Growth estimation

The Patent Growth is an index that measures the evolution of patent applications over time. By studying the portfolio of a sector, it is possible to observe different profiles and these profiles depend on the filing strategy implemented by the applicants. Therefore, a growing portfolio may indicate that the applicants in the sector are in the phase of construction of their portfolio. When a stabilization of the number of filings is observed, it can be explained by: a stabilization of research and development budgets, which leads to a flow of patent applications that is more or less constant without too much selectivity applying for patents or a decline in the number of patents filed that is generally symptomatic of a substantial decline in research and development or intellectual property budgets.

The method adopted to measure the economic convenience to guide the choice of technology replacement for a product is the patent costs method based on patent growth index.

Patents are a very rich public source of information on innovation and technology. They have the ability to predict the innovative capacity of a technology and are able to measure the performance of companies, technologies and sectors. The analysis conducted in this dissertation takes into account the patent cost which is a function of the number of patents, time and internationalisation (number of geographical extensions).

In this way, it is possible to assess the innovative efforts of all the companies in the world that are doing research and developments and investing in the technologies under investigation. The indicator is also especially useful to assess whether a new technology is replacing an old one in relation to the expenses that are being incurred.

The choice of the cost-based method for estimating patent costs is the result of comparative work that takes into account all methods in the literature (Section 2) relating to the estimation of patent costs. Each method was tested by the candidate for the case studies followed. A comparative table showing the problems encountered when applying these methods is shown in Table 15. The methods chosen to carry out this preliminary analysis are: Cost based, Market data and the Economic benefit method.

Table 15. Comparative analysis of the main methods for estimating the value of a patent. The main problematics encountered during their application to case studies are reported for each of these methods.

Method name	**Problematics in its application for the current research**
Cost based method	The method takes into account only what is spent in the past and completely disregard the economic benefits that could arise from the use of the patent in the future.
Market data method	Since there is no real regulated patent market and there is no obligation to make public the information relating to purchases and sales, it is almost always impossible to know about a transaction relating to a patent similar to the one to be assessed.
Economic benefit method	The method requires the definition of projected revenues from the sale of patented products and the corresponding production cost projections over the patent term. In practice it is necessary to make revenue and cost forecasts for the next 15-20 years. In essence, all methods based on future economic benefits require that a detailed and sustainable Business plan for the production and sale of patented products has been developed.

Based on the limitations encountered during the applications of the various methods presented in Table 15, the one adopted for the analysis is the Cost-based method.

Il criterio alla scelta di questo metodo per la stima economica dei brevetti è frutto di un processo di esclusione. With the considered method, it is possible to easily recover all costs, equivalent to filing and maintenance fees, incurred by all players who have filed at least one patent.

The necessary information is easily retrievable from the websites of the offices in charge of administrative procedures related to the protection of intellectual property. From patent databases, on the other hand, it is possible to extract all complementary information regarding priority dates, first filing dates and territorial extensions for each patent. In addition, it is not necessarily to make any future assumptions or forecasts, as is the case with the other methods described.

The method followed for the determination of the analysis of patent growth based on cost based method was carried out for each investigated alternative technology following a rigorous step-divided procedure. The starting point deals with the definition of the time period in which the analysis is performed.

The Orbit Intelligence patent database is queried to identify and collect the patents regarding the identified product. Title and abstract of each patent are manually checked to exclude the non-pertinent ones from the pool. Patents families are then classified according to the date of first publication year. This criterion was considered because patents are generally published eighteen months after the earliest priority date of application. Then, the collected numbers of patents referring to each publication year were plotted in a dispersion graph where the x-axis refers to the years, while the y-axis to these values.

Finally, the cost of each patent is calculated by applying the Cost-based method. This method was carried out individually for each patent by considering the total amount of the discounted costs incurred by the owner for filing, patent extensions and maintenance cost fee over the years.

The main difficulty of this method is to retrieve all the fees required by the various jurisdictions to proceed with the filing, subsequent granting and maintenance. This procedure must be carried out manually. A patent can be extended in several states based on the principle of territoriality. This decision is the result of strategies of the applicants.

These strategies can distort the entire analysis if not understood correctly. Therefore, the three main strategies policies have been studied and are presented below:

- The national strategy: in this case, the application is submitted directly to the intellectual property office in which the applicant is interested. If it is decided to extend protection to other countries, it is necessary to follow the national procedures of each country and consequently to obtain as many concessions as there are countries that have issued the title. The procedures of each individual Country differ significantly, as can the application fee and the amount of maintenance payments.
- The European patent strategy: a single procedure at the end of which it is obligatory to choose the countries in which to transform the granted European patent and thus obtain as many patent titles as there are so-called designated countries. The procedure provides for the submission of the application to the European Patent Office within 12 months from the national filing date or directly in the case where there is no intention to claim priority; the Office verifies the formal and substantial requirements (novelty, inventive step, industrial applicability) or considers the search report issued valid in the case of an invention application claimed as a national priority.
- The international strategy: there is an agreement between a significant number of countries for which it is possible, with a single extension application and without the use of a legal representative in each country, to obtain as many patents as there are designated countries. This agreement is called the Patent Cooperation Treaty (PCT). The main differences between the European Patent and the PCT system are: the PCT system does not lead to a single grant that is subsequently accepted by the designated States, but is a single centralised procedure for filing an international extension application that will, however, undergo further examination by the designated States according to their individual national laws. The PCT system covers a much wider range of countries than the European Patent, including non-European countries. The authority responsible for accepting the international application is the World Intellectual Property Organization (WIPO): it accepts the application and the filing, international search and examination fees.

WIPO then issues the search report on novelty, inventive step and industrial applicability and forwards it to the applicant.

Depending on the filing strategy followed by the applicant, a patent or patent family is obtained. A database such as Obit Patent Intelligence allows the extraction, for each individual patent, of the following: the priority, filing, publication and grant dates; the designated states in the case of a patent family and a register showing all fees incurred by applicants.

In addition, the database makes it possible to extract the number of pages for each patent and the number of legal claims for each patent procedure, subdividing them by independent and dependent claims. Number of pages and claims influence the cost of patent proceedings.

Methodologically, as a first step, all fees were extracted from each individual intellectual property office. As an example, Table 16 shows all the cost items related to the procedure for filing, obtaining and maintaining an Italian patent. The source of the data is the Italian Patent Office website (https://uibm.mise.gov.it/index.php/it/brevetti/deposito-di-una-domanda-di-brevetto/quanto-costa-brevettare).

Table 16. Fee schedule for patent filling, maintenance and concession in Italy. Data were extracted from the Italian Patent Office.

Patent fees category	**Patent fees category description**	**Sub-category description**	**Fee (€)**
Patent application filling fees	Description, summary, claims and draws are in telematics mode	-	50
	Description, summary, claims and draws are in paper format	If description, summary, claims and drawings do not exceed 10 pages	120
		If the description, summary, claims and drawings exceed a total of 10 pages but do not exceed 20 pages	160
		If the description, summary, claims and drawings exceed a total of 20 pages but do not exceed 50 pages	400
		If the description, summary, claims and drawings exceed a total of 50 pages	600
	Number of claims	Every claims over 10th	45
	Search report	For search report drawn up by the European Patent Office	200
Rights to keep the patent alive beyond	From 5th to 14th year	Fifth year	60
		Sixth year	90
		Seventh year	120

the fourth year of filing		Eighth year	170
		Ninth year	200
		Tenth	230
		Eleventh	310
		Twelfth	410
		Thirteenth	530
		Fourteenth	600
	From 15th to 20th year	Fifteenth year and thereafter up to the twentieth year	650

The patent fees category and sub-category s are the same in every state. What varies are the amounts and, for some Countries, the (e.g. United States), the rights to keep the patent alive, are not to be supported every year, but in three-year cycles. These cost items are the ones considered for the analysis.

However, each public office in charge of administrative procedures requires the payment, at its discretion, of additional cost items, such as late payment fees, transcription fees, stamp duties and any secretarial fees.

These amounts are only to be incurred in special cases and vary depending on the public office and the rules due to administrative burdens. Therefore, these cost items are not of primary importance for the analysis and are not easily available. For these reasons, the starting assumption is that all patents considered had no problems with payment delays and complied with the standard schedule above.

This procedure was carried out in a similar way for all countries. At the same time, the costs for the European and international procedures were collected.

The next step is to extract all patents relevant to the technology and application from Orbit Patent Intelligence. From the study carried out by analysing the various fees, the information that should be extracted for each patent and necessary for the calculation of the patent cost is: date of first filing, characteristics of the patent family (number of territorial extensions), number of claims and number of pages.

Finally, based on the information obtained, the Cost based method is applied, with currencies actualised.

Figure 25 summarises, in the form of an infographic, all the steps taken for the Patent Growth estimation method.

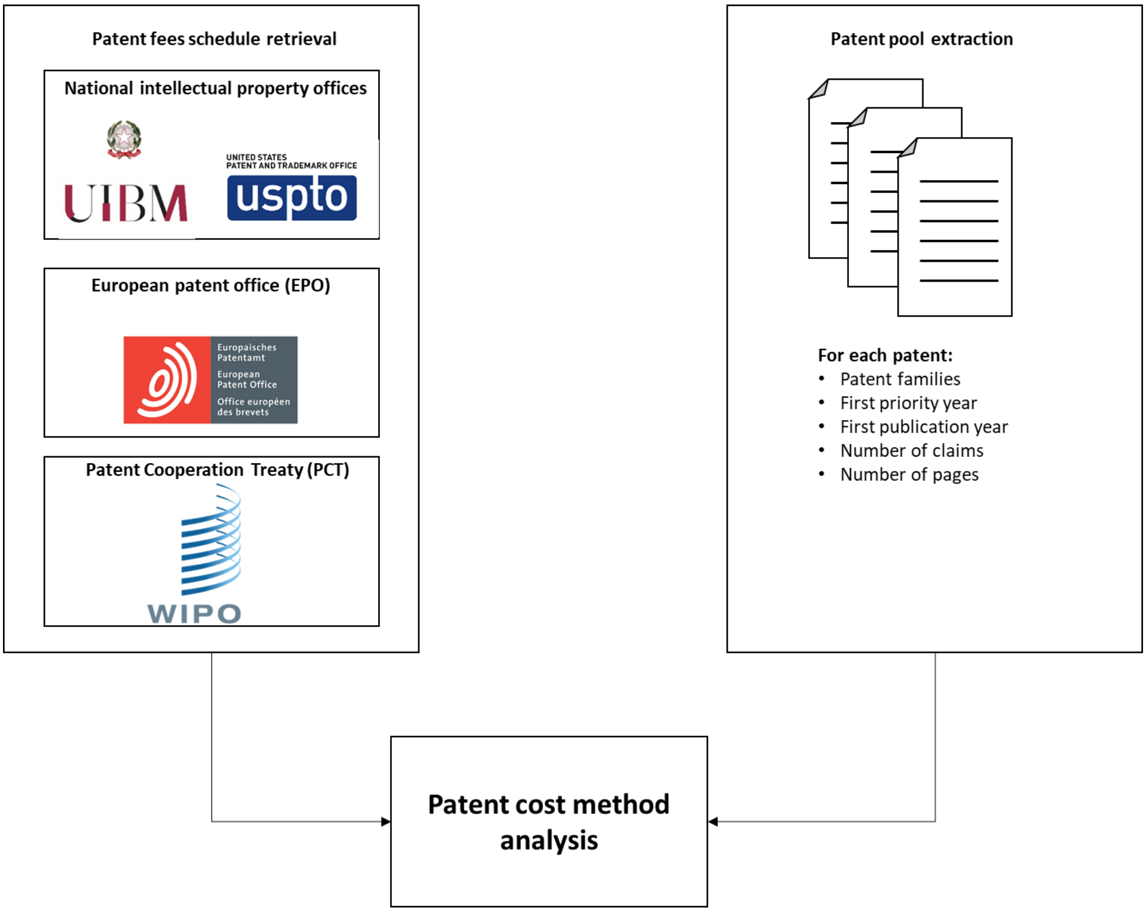


Figure 25. Schematic representation of all the steps taken to evaluate the Patent Growth estimation.

6.2.2. Economic Growth estimation

In addition to the economic estimation defined by means of the patent cost analysis, the Economic Growth analysis is introduced to estimate, based on data provided by company financial statements, the company result before taxes and financial charges.

In this way, it is intended to provide researchers and entrepreneurs with a suggestion as to how much income they are able to generate for companies that are identified as being interested in technology or products similar to the one under study.

Economic Growth is economic trend evolution over time defined as the Earnings Before Interest and Taxes (EBIT), a measure of a firm's profit that includes all incomes and expenses (operating and non-operating) except interest expenses and income tax expenses. EBIT is a margin that measures the company's profit deriving only from ordinary operations and its result is the difference between the revenues obtained from the sale of goods or services subject to the company's activity and the costs incurred to realize them (commercial expenses, production costs, administrative and general expenses).

The choice of the EBIT indicator is due to the fact that, with this indicator, it is possible to define the income that the company is able to generate before the return on capital, including both debt and equity. Both indebtedness and equity are two factors of interest from the point of view of technology transfer and for a TTO that, in this way, is able to analyse the past situation of other companies and suggest possible strategies to research groups that want to found a spin-off to continue the exploitation of the product being researched.

The method adopted to obtain the economic growth value started with a market analysis. This latter was carried out by analysing the websites devoted in collecting companies' information, typically categorized by product category. Once all the companies have been identified, the financial statements during a specific period were retrieved by using Orbis database, from which the EBIT value was calculated according to the following formula.

$$EBIT = Revenue - Cost\ of\ goods\ sold - Operating\ Expenses$$

Where Revenue is the income or increase in net assets that an entity has from its normal activities. In the case of a business, usually from the sale of goods and services to customers. Cost of goods sold is the carrying value of goods sold during a particular period. Costs include all costs of purchase, costs of conversion and other costs that are incurred in bringing the inventories to their present location and condition. While Operating expenses are an ongoing cost for running a product, business, or system.

The sum value of all EBIT found is calculated over the total number of companies found and classified for each year of the analysis. All the costs of the previous year of analysis are actualized to the current currency.

6.3. Comparing Market and Economic potential

The objective of the presented methodology is to suggest to research groups and company experts how to measure the technological substitution of two competing technologies in order to achieve the best investment prospects and to facilitate technology transfer.

In order to measure the feasibility and opportunity to transfer a technology into each of the new products identified in the previous steps, the research carried out in this dissertation focused on the proposal of a four-level evaluation of the technological substitution.

The objective of this tool is to initially carry out a technological comparison to suggest a ranking between the identified applications, by proposing a novelty analytical tool called Technology substitution graph. In Figure 26, the four-level evaluation of the technological substitution, also called technology substitution graph, is presented. This tool is based on two dimensions: a technical perspective (Transfer potential) to measure the potential of technology substitution evaluation based on market potential and an economic perspective based on economic trend evolution over time defined as the Earnings Before Interest and Taxes (EBIT) and patent costs of the alternative technologies for a determined period of time.

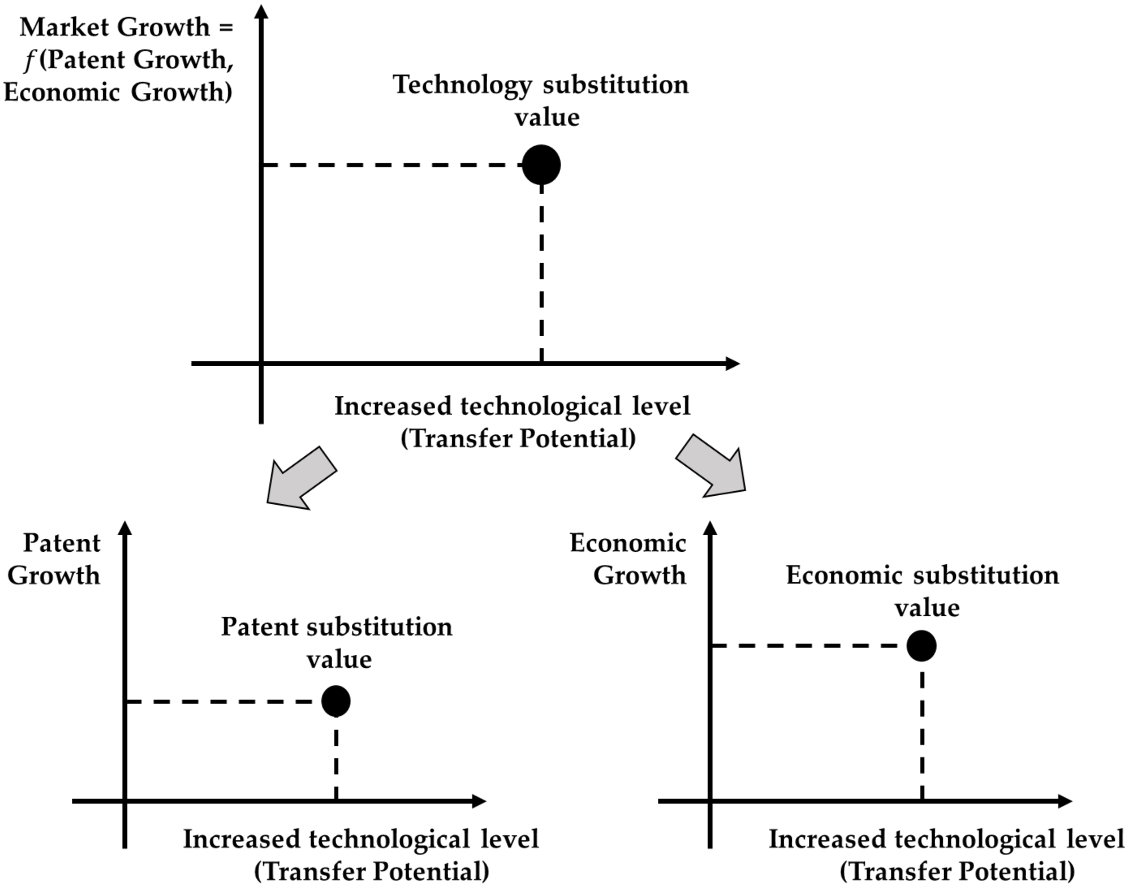


Figure 26. Technology substitution evaluation graph.

As shown in Figure 26, the Technology substitution graph is a function of two different matrices that analyse the relationship that is established in the trend over time of two different variables: patent growth, the economic trend of the net operating margin. In particular, Transfer Potential is an index that measures the opportunity of actuating the technology substitution. Patent Growth is an index that measures the evolution of patent applications (first publication year) over time, making it possible to evaluate the dynamics of inventiveness of the portfolio studied. The Patent Growth is defined as the ratio between the sum of the costs of all patents for a given period of the two alternative technologies. While Economic Growth is an index that measures the economic trend evolution over time defined as the Earnings Before Interest and Taxes (EBIT), a measure of a firm's profit that includes all incomes and expenses (operating and non-operating) except interest expenses and income tax expenses.

Both Patent Growth and Economic Growth have previously been shown in Section 6.2.2 of this dissertation. The Transfer potential indicator, instead, is evaluated starting from the Market potential analysis and it is a new indicator introduced for this analysis.

Table 17 summarises all the steps that were taken to carry out the analysis for defining the Transfer potential indicator, starting with the assessment of each requirement for the technology considered by applying Ulwick's market potential formula. The parameters that compose the market potential formula are divided into importance and satisfaction. Both evaluated through interviews with experts. As for the next step, regarding the comparison of the technologies under investigation, the Product value (PV) is the indicator that was introduced to assess the market potential of a specific product and automatically extracted through semantics. Finally, a Transfer potential (TP) indicator measures, by dividing the Product Value previously evaluated of the two competing technologies, the potential of technology substitution.

Table 17. Sequential steps for the evaluation of technology substitution starting from the market potential technique.

Steps	Formulas
Evaluation of market potential (MP) Ulwick (2002)	$MP_i = 10 \cdot (1 + \frac{Ii}{100} + (\frac{Ii}{100} - \frac{Si}{100})$ MPi = market potential of the requirement i for the technology considered; Ii is the importance of the requirement i Si is the satisfaction of the requirement i.
Product value (PV)	$PV_k(m,p) = \sum_{i=0}^{n}[S_i(m) * MP_i(m)] / \sum_{i=0}^{n}[S_i(p) * MP_i(p)]$ Si(m)and Si(p) are the satisfaction of two different technologies m and p in regards to the requirement i.

Transfer potential (TP)	$$TP\ (Transfer\ potential) = \frac{PV\ (Tech_{new})}{PV(Tech_{old})}$$ The Transfer potential value of a certain application is the ratio between the Product values (PV) of the technologies. If TP>1 the technology transferred is recommended. If TP≈1, there is no evidence to recommend a technology transferred. If TP<1, the technology transferred is not recommended.

The Technology substitution graph, therefore, is a function of three indicators: Patent Growth and Economic growth, which form the y-axis, and Transfer potential, which forms the x-axis. The first two indicators are of an economic nature while Transfer potential is of a technical nature and is generated from the market potential.

The intersection of the Patent Growth and Transfer potential values generates the Patent substitution value. Similarly, the procedure for determining the intersection value of Economic Growth and Transfer potential is carried out. The point of intersection of these values is defined as the Economic substitution value.

In order to measure the technological substitution of the two competing technologies for application, the economic growth and patent growth over time should be assessed against the transfer potential, which is the same value for both. This can be assessed in matrix form, each for the previously defined variables.

For economic growth, the y-axis of the matrix is defined as the weighted moving average (WMA) of the calculated EBIT values over time. The same can be defined for patent growth where the y-axis is the weighted moving average (WMA) of the total sum of patent costs over time.

The Weighted Moving Average (WMA) is a classic arithmetic average of prices that gives more weight to the most recent data and less weight to data that are more distant in time. The mathematical formula for calculating the WMA is as follows:

$$WMA = (C_1 * 1 + C_2 * 2 + C_3 * 3 + \cdots + Cn * n)/(1 + 2 + 3 + \cdots + n)$$

Where C1,..., Cn are the economic value and 1,...,n are the weights assigned to each value. By calculating the weighted moving average, we obtained two comparable values for the two quantities considered for this research.

At the end of these analyses, the values obtained from the two graphs can be compared and plotted in the Technology substitution graph, presented in Figure 27.

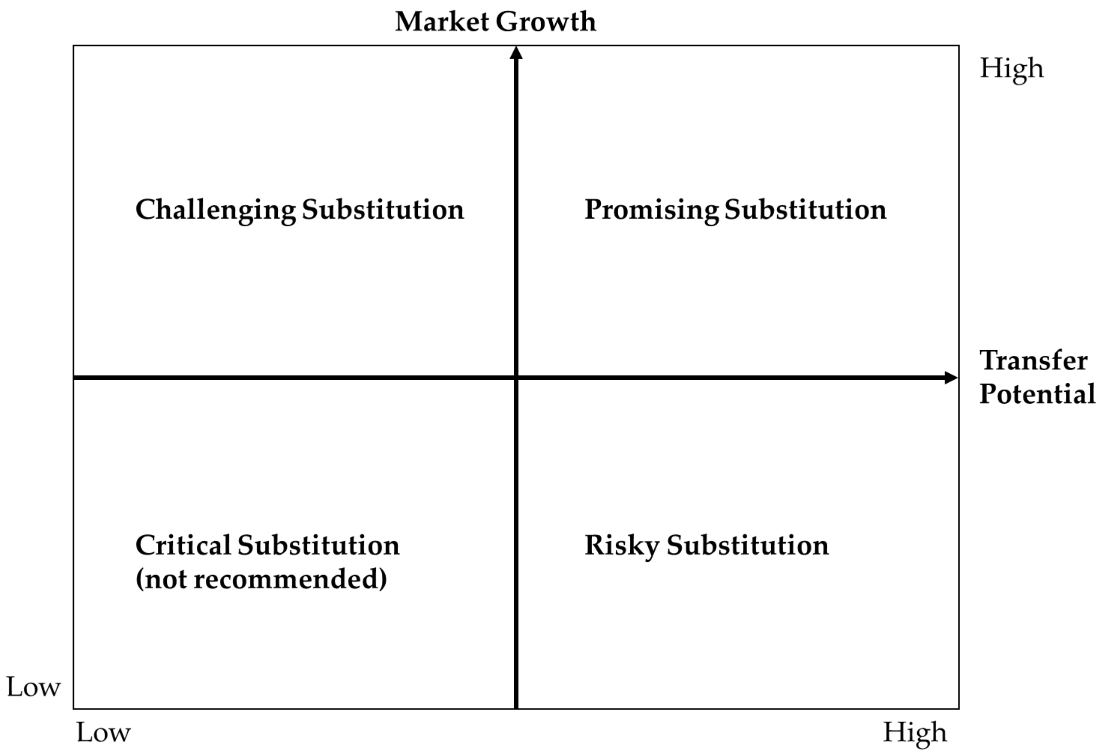


Figure 27. Matrix representation of the Technology substitution evaluation graph.

Referring to Figure 27, the first quadrant, where TP>1 and MG>1, the technological substitution is promising because there is an economic advantage. In the second quadrant, where TP<1 and MG>1, the substitution is challenging, because economic margins for the company are ensured but technological substitution has low potential. In the third quadrant, where TP<1 and MG<1, the substitution is critical because no convenience in carrying out the technological replacement is obtained. Finally, in the fourth quadrant, where TP>1 and MG<1, the substitution is risky and not recommended, because there is a positive potential for technological substitution, but negative economic margin for the company.

Finally, Figure 28 summarises, in the form of an infographic, all the steps presented in Section 6.3 for the comparison of Market and Economic potential.

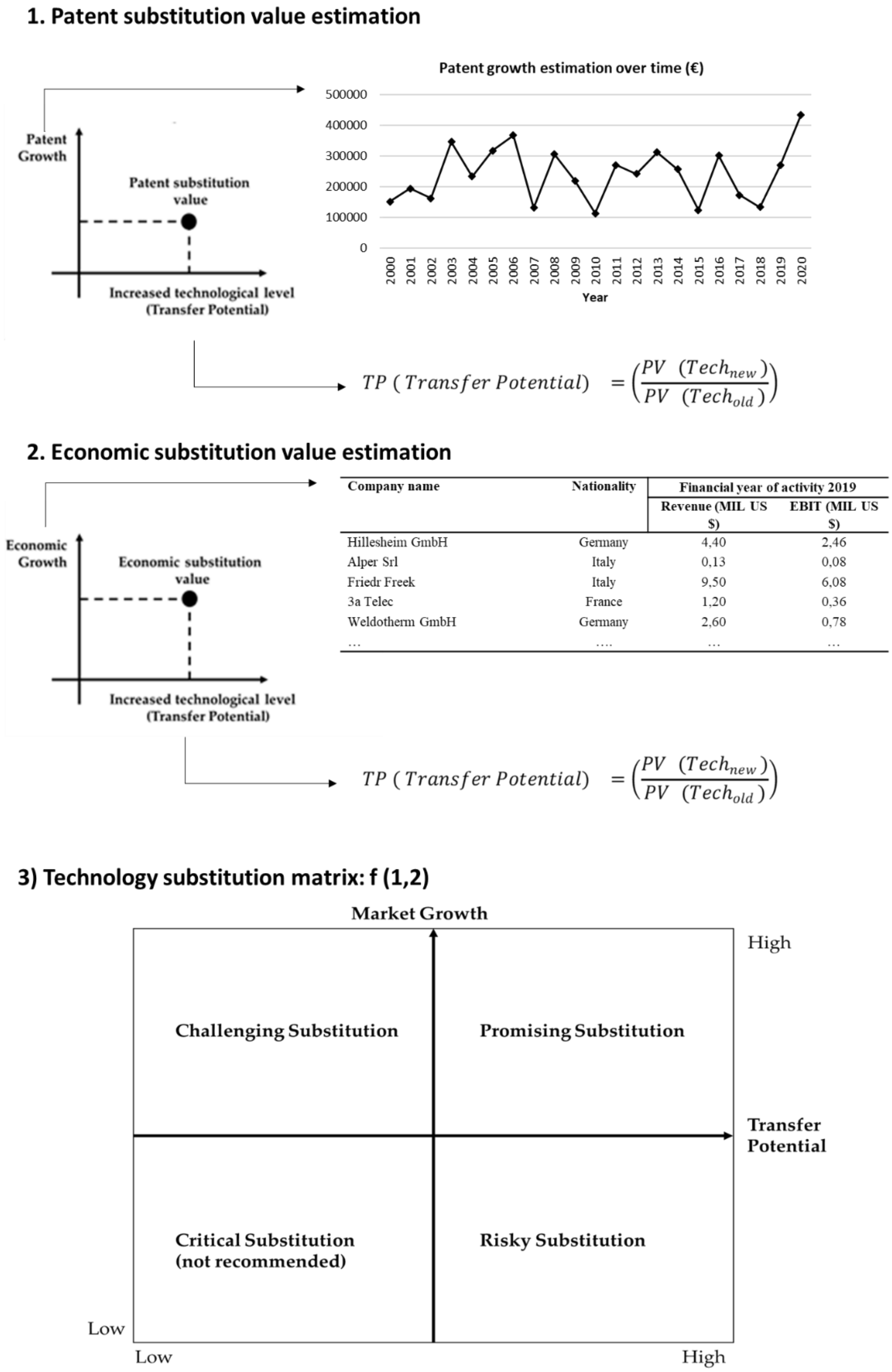


Figure 28. Schematic representation of all the steps taken to compare Market and Economic potential.

7. Case study: Business evaluation

This Section exemplifies the application of the proposed method with a real case study concerning the use of current-carrying carbon nanotube filaments, woven into the weave of a fabric, which are used to heat by the Joule effect in a uniform and constant manner, with greater efficiency than more common filaments, such as those made of copper.

The aim of the research conducted was to suggest all possible fields of application for the technology, providing a ranking of the most promising from both a technical and an economic point of view.

In the following sections, the different steps of the methodology are exemplified according to the case study.

7.1. Market potential

The requirements are assessed individually by experts in the field using the market potential tool. In this case study, the evaluation of importance and satisfaction was carried out by the owner of the company. As the company is a start-up, the owner has a visibility of the entire process, therefore its competence is adequate for the purposes of this analysis. Importance can be summarized as the degree to influence the customer decision and it is reflected in goal-oriented search attributes that consumers actively look for in the target product and consider when making a purchase decision.

Satisfaction is a measure of how products and services supplied by a company meet or surpass customer expectation and it has been evaluated by the marketing staff of the company. The final evaluation value of each requirement was obtained according to a group-based consensus process to come up with the scores.

The assessments of importance for each parameter were obtained by means of an interview. In this specific case, before carrying out the interview, quantitative analysis based on brochures, patent intelligence and competitor analysis were shown to the expert to make the assessment as reliable as possible.

As the market potential analysis that will be applied to heating fabric mat presents two technologies, carbon fibre and copper wire, we want to evaluate the degree of technological substitution of carbon with respect to the more established technology of copper wire.

Table 18 provides the evaluation of requirements by means of the interview of the expert in the field according to the Market potential technique.

Table 18. Market potential analysis for heating fabric technologies of carbon fibre and copper wire related to heating mat application.

Requirements of Heating mats	**Importance %**	**Satisfaction % (Carbon)**	**Satisfaction % (Copper)**	**Market Potential (Carbon)**
Increase flexibility	90	70	50	21
Reduce thickness	0	60	40	4
Easy replacement	0	30	30	7
Average temperature	0	100	100	0
Corrosion resistance	0	100	20	0
Ergonomic	30	100	100	6
Heat uniformity	30	100	90	6
Low voltage	90	80	20	20
Reduce weight	0	100	100	0
Cable dimension	0	100	100	0
Temperature/heat precision	30	80	80	8
Heat dissipation	0	60	60	4
Thermal inertia	30	80	50	8
Wave emission (medical)	30	40	10	12

To suggest and objectify the assessment of requirements, in addition to the patent intelligence charts presented in Section 6.1, exemplary graphical representations of web traffic analysis that can be used to support the decision-making as complementary indicators. Specifically, Figures 29 show web trends of heating mats application over time in United States territory and they are generated by Semrush software (Semrush, www.semrush.com), a tool to identify market trends and best industry practices.

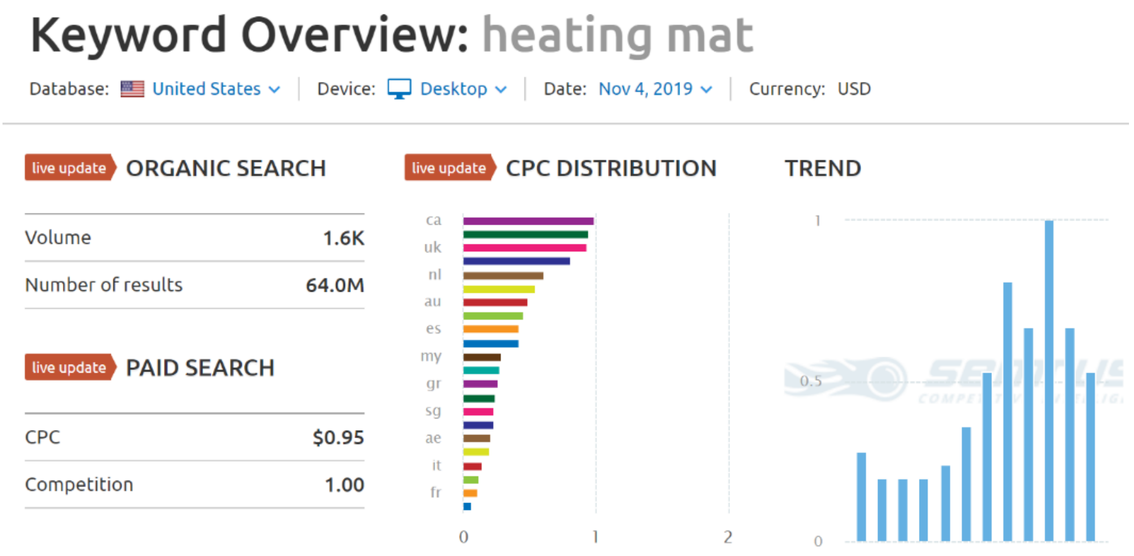


Figure 29. Example of web marketing analysis related to the keyword of 'heating mat' in USA. Indexes Shown: Volume (average number of monthly searches), CPC (Cost Per Click: the average price in US $ advertisers pay for a user click), CPC distribution over countries and Trend (search volumes over the last twelve months). Screenshots from Semrush tool.

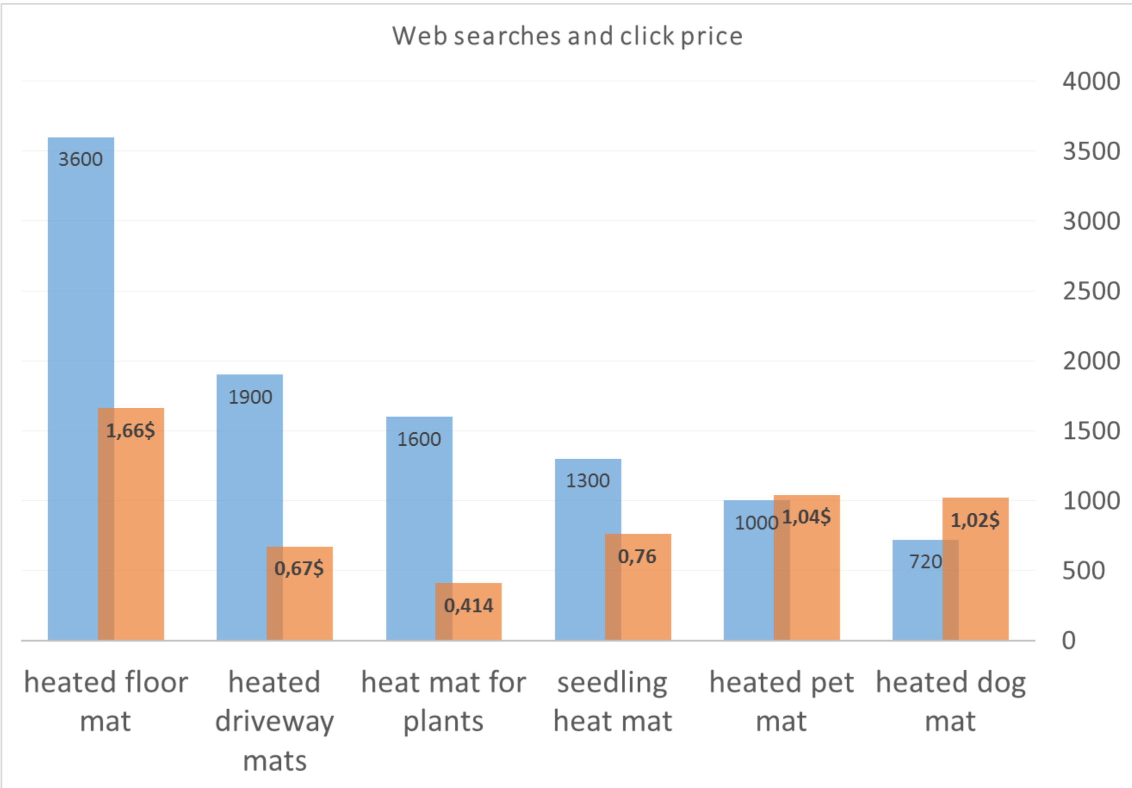


Figure 29. Example of web marketing analysis. The bar chart shows the one-month web searches and the click price of the top ranked keyword combinations about 'heating mat' in USA. Screenshot from Semrush tool.

The result of this first assessment shows that heating mat carbon fibre technology demonstrates a greater flexibility compared to copper wire heating mat. This requirement proves that as a heating technology, carbon fibre has a good application prospect also in different products. Carbon fibre technology can better satisfy also low voltage requirement. In regards to the characteristics of carbon fibre flexible heating body working under low voltage, the battery power supply type can be used as the power supply of the heating mats. More than that, carbon fibre technology satisfies also heat uniformity, thermal inertia and wave emissions (medical). In comparison with a traditional electric heating wire heating, carbon fibre has a rapid temperature rise. When the power is disconnected, the temperature recovery speed is fast. Therefore, the carbon fibre heating clothing has the characteristics of accurate temperature control.

Starting from the market potential results found in Table 18, evaluated for each single requirements, the next step consists in the evaluation of the market potential of the technology to be transferred. In this regard, the candidate formulated an index called Product Value (PV), which takes into account the individual market potential for each requisite and the satisfaction value of the two technologies in question.

In this way, the product value of both carbon fibre technology and copper wire technology was calculated. The calculations and formulas are shown in Table 19. As far as the market potential analysis is concerned, the product value of carbon fibre technology is twice as high as the value of copper wire technology (70 vs. 45.4). Therefore, using the Product Value values just found, it was possible to calculate the Transfer Potential value, which measures the substitution potential of the technology.

Table 19. Product value and Transfer potential evaluation of heating mats application.

Heating mat application	**Carbon fibre technology**	**Copper wire technology**
Product Value (PV) Evaluation of the market potential of the technology to be transferred	70	45.4
Transfer Potential (TP) Measure the potential of technology substitution	1.54	

The Transfer Potential of Heating Mat is equal to 1.54. From Table 19 it is possible to observe that TP is >1. This means that the technology transferred is recommended. The carbon fibre technology has a product value (PV) higher than the copper wire technology because the carbon fibre better satisfies the requirements. Over the years of investigation, carbon fibre technology has shown greater flexibility and corrosion resistance than alternative technology. These results are also scientifically proven by the work of Liu et al., (2020) and Buyakov et al. (2019).

7.2. Economic potential

7.2.1. Patent Growth estimation

To perform this analysis, the starting point is the patent pool constructed for the heating mat application and presented in Table 20. The total patent pool relevant to the technology consists of 877 patents obtained by means of the search query: *(heat+) 1D (fabric+) AND (mat?)/TI/AB/TX* of which: 129 using copper wire technology and 748 carbon fibres.

All patents were analysed manually in order to check relevance to the application and exclude irrelevant patents. Five patents were excluded during this phase for the reasons provided in Table 20.

Table 20. List of patents, by number, that are excluded from the initial pool and the reasons for exclusion of patents in the starting pool.

Patent number	**Reasons for exclusions**
KR20100137650	The object of the invention concerns a bunner controller of a portable boiler used for heating mat and heating air mat. Heating mat are provided to prevent a hot water circulation pipe inside a heating mat from being folded and pressed by arranging the hot water circulation pipe in a sponge.
KR20140039368	Hot water heating mat using loess block.
EP2526294	The present invention relates to a blade for a wind turbine. The heating mat is not the object of the invention, but a component that is used to heat the blade of the turbine, the object of the invention.
EP2526294	Heating mats arranged in a loop on a blade.
KR101533038	Hot water circulation device for heating mat. The object of the invention is the system of tubes for the circulation of water inside a heating mat product.

Excluding the patents presented in Table 20, the pool now totals 872. The patents were then subdivided by year using the year of first publication as a discriminant.

Patent applications are generally published 18 months after the earliest priority date of the application (in some case three months, but it must be defined a priori by the applicants of the patents). Prior to that publication the application is confidential to the patent office. After publication, depending upon local rules, certain parts of the application file may remain confidential, but it is common for all communications between an Applicant (or his agent) and the patent office to be publicly available.

The publication of a patent application marks the date at which it is publicly available and therefore at which it forms full prior art for other patent applications worldwide. The patent numerosity of heating mat application are shown in the graph as an example and they are reported in Figure 30.

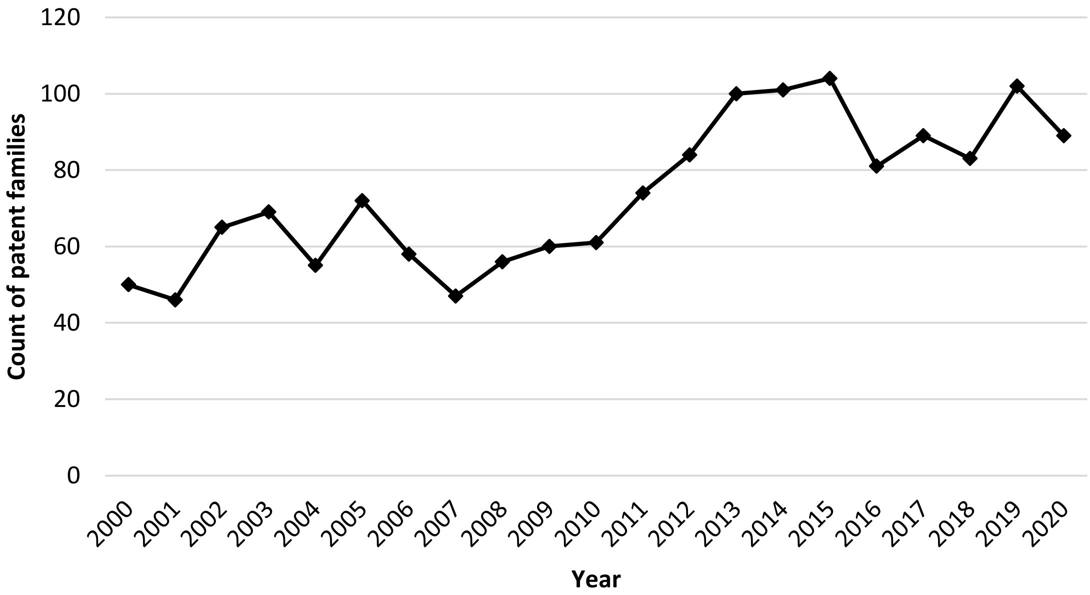


Figure 30. Graphical representation of patents related to heating mat divided by first publication year.

Then, the cost-based method was applied to calculate the patent cost. A partial list of cost items with related costs is provided in the table below, relating to the 2019 year of publication (Table 21). The same procedure is carried out for all the time period of analysis. Costs relating to the years before of 2020 have been actualised at the current rate to have the same normalised currency. The method of calculating the patent cost was carried out for each patent family for each year of publication. the method sums up the cost of filing and maintaining each patent extension. it does not consider costs other than taxes to be paid to the relevant patent office.

Table 21. Partial list of cost items with related costs for 2019.

Patent Number and Title	**Patent Cost (€)**
KR102141576: Carbon fibre heating mat	238
CN110424154: Surface metallization method of activated carbon fibre heating mat felt for hydrogen storage, activated carbon fibre felt and application thereof	830
CN110662315: Processing method for carbon fibre heating mat	830
KR20200113398: Heating mat for winter fall prevention using carbon fibre heating mat and manufacturing thereby	294
KR20200085149: Heat-generating mat with carbon fibre heating device	252
KR102027092: A carbon fibre heating mat element capable of suppressing a stagnation phenomenon and a manufacturing method thereof	308

For each year, the sum of each individual patent filed in that year is calculated. The cost of a patent increases according to the number of claims, number of pages, maintenance fees and extensions of the patent family.

Figure 31 provides a graphical representation of the total cost of patent families, conducted with the cost-based method, for the time period 2000-2020. Subsequently, the total cost was defined divided by the two technologies of interest: carbon and copper wire.

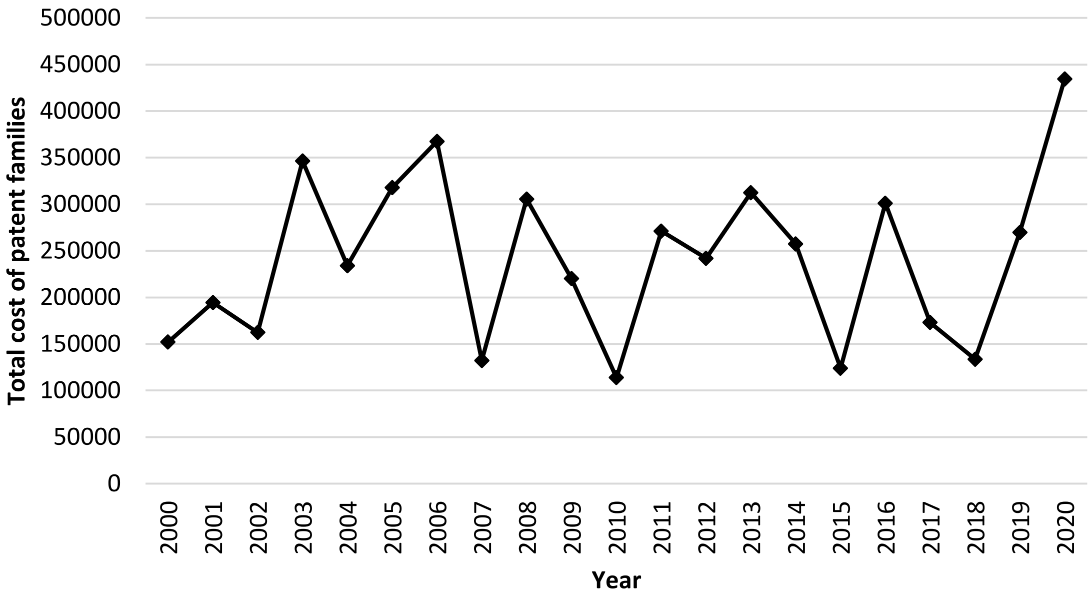


Figure 31. Graphical representation of the total cost of patent families of heating fabric by first publication year.

7.2.2. Economic Growth estimation

The second indicator used to define the Economic potential is calculated from data obtained from the balance sheets of companies and is aimed at quantifying the business results of companies that invest, produce and sell the technology under investigation. In particular, a comparison will be made between the incomes of companies producing heating mats with carbon wire and companies producing heating mats with copper wire technology.

To calculate economic growth, the EBIT Earnings Before Interest and Taxes indicator is used as a reference.

The first step is to identify a sample of companies producing the application under study from which it will then be possible to extract EBIT for a time reference period.

n order to identify the companies, an initial search was made by consulting the Orbit Patent Intelligence database, selecting the patent applicants from the heating mat pool, appropriately divided by technology. Universities and research institutes were excluded from the list of applicants, leaving companies in the count. The search was extended by performing a web search (e.g. commercial catalogues from Amazon amazon.com, E-bay ebay.com). Each identified company was then analysed manually by extracting the commercial catalogues (as shown in Table 22).

Table 22: Example of information extracted from documentary sources for the 'heating fabric' case.

Source collection	**Collection topic**	**No. Doc.**
Catalogues	Heating mats	83
	Heating mats by copper wire	51
	Heating mats by carbon fibre	22

Of all the companies identified, the main focus was on those that only produce heating mats. Therefore, single-product companies that are present on the market with different customisable options of the same application. By adopting this hypothesis, it was easier to proceed with the extraction of EBIT from the financial statements, safe in the knowledge that the economic values refer to the financial situation resulting from the sales of that product.

According to market analysis carried out by consulting the websites specialised in collecting company information and/or classifications of companies by product category, 50 companies producing only Heating Mat applications were retrieved. Nineteen of them produce only Heating Mat application with carbon wire technology, while the companies for both technologies are single-product companies.

The analysis was conducted by considering a period of 5 years, from 2015 to 2019. The reasons for choosing a period of 5 years are to be found in the limitations imposed by the program we used to extract the financial statements from which the relevant economic data for this analysis were calculated. the financial statements could be obtained from 2015 to 2019, the year of the last financial statements.

Once all the companies have been identified, by using Orbis software we extract all the financial statements for a specific year of activity. From the annual financial statements, for each company, the EBIT is identified.

$$EBIT = Revenue - Cost\ of\ goods\ sold - Operating\ Expenses$$

Table 23 provides, as example, an evaluation about EBIT values of the main identified companies for 2019 year of activity.

Table 23: Evaluation of EBIT values from the companies identified. The reference year of the analysis shown in the table is 2019.

Company name	**Nationality**	**Financial year of activity 2019**	
		Revenue (Mil $)	**EBIT (Mil $)**
Hillesheim GmbH	Germany	4,40	2,46
Alper Srl	Italy	0,13	0,08
Friedr Freek	Italy	9,50	6,08
3a Telec	France	1,20	0,36
Weldotherm GmbH	Germany	2,60	0,78
Tempsens	India	0,12	0,03
Devi by Danfoss	Sweden	0,10	0,03
Mat and Sons Heating Inc	USA	0,14	0,04
Well-being water heating mats, Inc.	USA	0,07	0,02
Smart massage mat LLC	USA	0,06	0,02
Ruian Zheyu Electrical Heating Mat Factory	China	1,45	0,44
Mat-Su heating	USA	0,03	0,01
Union Chill Mat Co	USA	5,10	1,53
Sun Ray Heating Inc.	USA	6,00	1,80
Sedes Group	Italy	1,24	0,37
Mrc Electrical Heat Trace Specialist Ltd.	Canada	0,97	0,29
Michaels Enterprises, Inc.	USA	1,00	0,71
Anderson-Bolds	USA	5,19	1,56
Ohmbo	Spain	0,44	0,13

Evaluation of the sum value of all EBIT found over the total number of companies was performed for each year of the analysis. All the costs of the previous year of analysis are actualized.

Finally, a sum of the EBIT for each year of analysis for all the industries taken into consideration was performed. The results are reported in Figure 32, that shows a comparison of total EBIT for each year of the analysis divided by the technology under consideration.

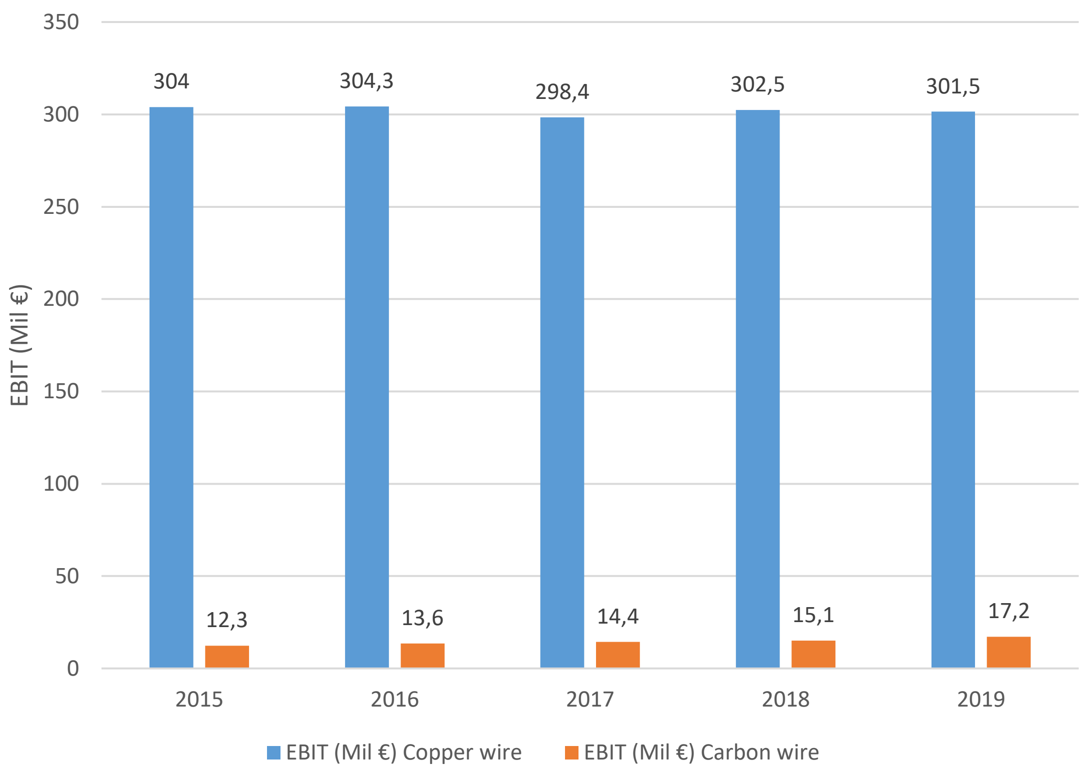


Figure 32. Comparison of aggregate sum of EBIT (in Mil €) for heating mat technology for 2015-2019-time period.

7.3. Comparing Market and Economic potential

To measure the technology substitution of the two competing technologies for heating mat application, it is needed to assess the economic growth and the patent growth over time in comparison with the transfer potential, that is the same value for both. This can be assessed in matrix form, each one for the variables previously defined.

For what concern the economic growth, the y-axis of the matrix is defined as the weighted moving average (WMA) of the EBIT values calculated over time. The same can be defined for the Patent Growth where the y-axis is the weighted moving average (WMA) of the total sum of patent costs over time.

The Weighted Moving Average (WMA) is a classic arithmetic price average that gives greater weight to the most recent data and less weight to data that is more distant in time. The mathematical formula for calculating the WMA is as follows:

$$WMA = (C_1 * 1 + C_2 * 2 + C_3 * 3 + \cdots + Cn * n)/(1 + 2 + 3 + \cdots + n)$$

Where C1,…, Cn are the economic value and 1,…,n are the weights assigned to each value. By calculating the weighted moving average, we obtained two comparable values for the two quantities considered for this research: economic and patent costs (Figure 33).

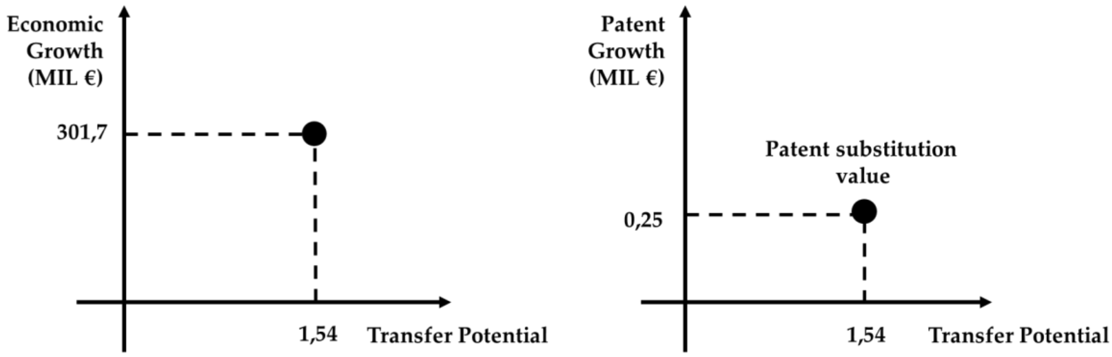


Figure 33. Graphical representation of the two matrixes for economic and patent perspectives. X-axis is the same value of Transfer Potential for the both of them, while, y-axis are the weighted moving averages for EBIT and patent costs.

Where Economic growth is the WMA of the EBIT of the companies producing heating fabric over time (from 2015 to 2019) and patent growth is the WMA of the patent costs over time (from 2000 to 2020). By comparing the two matrices above, it is possible to define Figure 34 for comparison of all variables of interest relating to economic and patenting trends for heating mat applications.

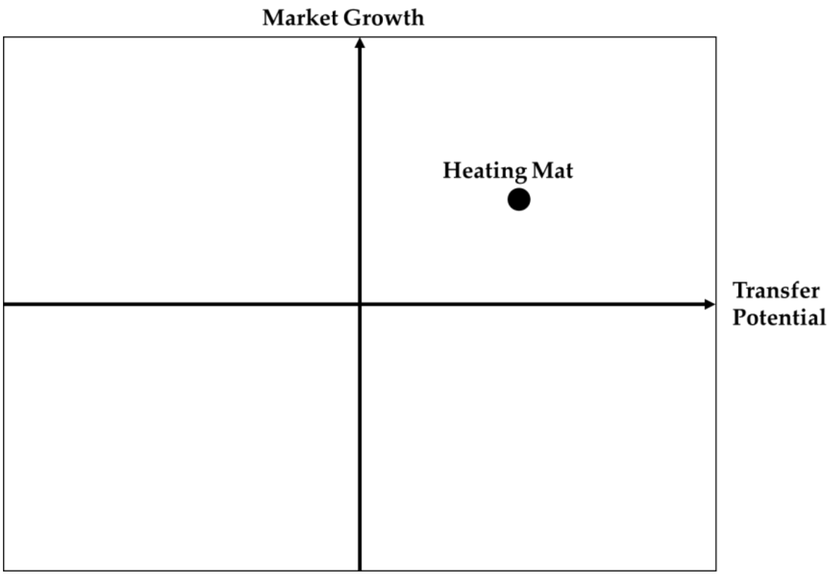


Figure 34. Technology substitution analysis of heating mat product.

As it can be seen from the matrix, all the technology substitution values identified for the years under investigation for heating mats, fall in the first quadrant of the technology substitution graph (promising substitution).

The findings of the technology substitution value are also confirmed by scientific literature. According to Mohammed et al., (2019), carbon fibre heating mat applications are a suitable solution respect to alternative technologies from both technical and economic solutions. From a technical point of view, heating mats constructed from carbon filaments are easy to manufacture and provide consistent heating. The temperature-time relations of carbon filament enable a constant temperature to be maintained longer than alternative technologies.

In an economic point of view, carbon fibre resistance heating fabric offers lower instalment and material cost. In addition, their material costs are lower compared to carbon fabrics. Similar considerations also in the works of Youe et al. (2016) which states that these mats could provide the basis for a new class of carbon fibre material.

8. Discussion of the results, implications and future developments

In addition to the case study shown in Sections 5 and Section 7, the proposed method was also applied to other case studies which the candidate had the opportunity to address during the PhD study and at the TTO. Such activities made it possible to highlight some peculiarities in the application of the method and differences from the first case study, which are reported and discussed in this Section.

During the collaboration with the research group "Textile, colour and finishing chemistry" of the University of Bergamo, coordinated by Professor Giuseppe Rosace, the proposed method was applied in its entirety, to compare and evaluate the introduction into the market of “Sol-gel composition for water-repellent finishing of environmentally friendly fabrics, obtained by application of an organic-inorganic ceramic coating with water-repellent, fluorine-free and formaldehyde-free properties”.

This product has been developed over the last three years and is currently a prototype fabric (Technology Readiness Level equal to five: in a broad context of applications, the laboratory prototype achieves the expected and predefined results). The application of the method to this product was mainly conditional on the identification of information and its evaluation in order to be able to write a patent, participate in a U4I Foundation funding call and prepare for a meeting with a possible buyer. Thanks to the information gathered with the proposed method, all these activities gave positive results. The patent application, in which the candidate was also involved as an inventor, was filed on the first of July 2021 with the filing number 102021000017357 and the title sol-gel composition for water-repellent finishing of textiles and its of fabrics and their preparation process at the Italian Patent and Trademark Office. Participation in the call for funding was rewarded with a grant of €62,000.

Differently from the case study of Section 5 and Section 7, in this case, the starting documentary sources were both scientific articles (6437) and patents (581), as the number of the latter was too small since the product covered is highly innovative. By analysing the scientific articles, the dependency patterns of the proposed method identified a rather small number of Functions compared to patents. In particular, the generic function "coating" and other very specific functions in the field of chemistry came up several times. This probably results from the high specificity of the articles in the chemical-textile field. As for the extraction of application fields (12) and requirements (21), the analysis of the articles proved to be extremely useful as it identified significantly more information than patents (6 application fields and 3 requirements), all of which was considered relevant by Professor Rosace, and therefore included in the proposed outputs.

Moreover, in this case, several experts participated in the evaluation of the requirements with the market potential through interviews compared to the previous case study. In addition to Professor Rosace, the other experts were the managing director of a Spin-off of the University of Bergamo, active in the same sector, and two entrepreneurs who collaborate with Professor Rosace as suppliers of materials and equipment for laboratory tests. With such a wider audience, the evaluations gathered were rather heterogeneous. In particular, in addition to the more technical aspects, which were mainly highlighted by Professor Rosace, the entrepreneurs also identified crucial marketing aspects. The difficulty in this case was to combine very heterogeneous requirements from different parties, whereas in the Case study Mr. Naimoli had simplified this phase by having an overview of the whole process that considered both the more technical and marketing requirements.

Instead, the application of the method to compare and assess the market introduction of “Photocatalytic ceramic foams for the removal of micropollutants.”, during the candidate's collaboration with the research group “Theoretical Chemistry” coordinated by Professor Isabella Natali Sora, highlighted critical points in the application of the results obtained. Although in this case the method had suggested several interesting fields of application for the product in question, the Professor's background, as well as her already established network of contacts and the academia network, strongly encouraged her to explore only one specific direction. This has reduced the time needed for the technology transfer phase that follows the application of the method, and the company has now participated in strategic sector calls for proposals. The product is currently being evaluated for funding in the field of water purification. Probably in this case, the main objective of the method is to identify that field of application which can be more easily undertaken at present.

Finally, the proposed method has also been applied in more scientific activities in Russo et al. (2018), Russo et al. (2021) and Bersano and Spreafico (2021). In these cases, although the method has not always been applied in full, some considerations have nevertheless emerged. In particular, the study of Russo et al., (2018) has made it possible to reason about the effectiveness of dependency patterns for Functions extraction and to confirm the effectiveness of those found when compared with the results obtained using two specific databases for biomimicry, i.e. Asknature and DANE. This may be due to the larger number of documentary sources taken into account by the proposed method, as these databases are based on only a few scientific biology articles, selected and readapted in textual format and partly in content.

Using expert interview and Market potential and possibly also the Economic potential of the proposed method, as presented, no longer to compare two existing technologies, albeit one in a prototype state, but to assess a possible technological trend between several products. In the paper Spreafico et al. (2021) the candidate has collaborated in charting a technology trend for four waste pyrolysis technologies on the basis of bibliometric analyses of scientific papers and patents. This study revealed a trend whereby laser pyrolysis outperformed three other alternative technologies, which were in turn ranked in descending order. The indices considered are the number of publications, citations received and the numerical values of two technical parameters of the pyrolysis reaction (reaction temperature and heating rate), guaranteed by the various technologies as explicitly stated by the documented sources consulted. In this perspective, the intervention of the expert for an assessment based on the requirements could prove to be crucial to confirm the trend highlighted in a purely bibliometric manner. In this sense, the development of the proposed method should pass from a rethinking of the involvement of the expert since the technologies considered are no longer two, but even more. In addition, one should also think about how to evaluate the satisfaction of the requirements and the economic parameters of the most technologically advanced emerging technologies that have little diffusion to date.

In the method presented, the semi-automatic analysis of document sources, which allows the identification of Functions, application fields and requirements, is carried out by means of a set of dependency patterns. However, the works of Spreafico and Spreafico (2021), and partly that of Spreafico et al. (2019), in which the candidate has collaborated, made it possible to show the need to customize the dependency patterns according to the research area in order to extract a greater number of information at the same time that it is also more relevant. In particular, the contribution relates to the circular economy and can be seen as a development of the method proposed in this area. The results achieved concern the identification of technologies and ways to recycle or reuse a waste, the products obtained from it and the possible uses of these products. The candidate's intention is to further investigate the effectiveness of customising the proposed method in the circular economy sector and also in other areas by acting appropriately in the method itself, e.g. with dependency patterns and possibly other parts of it.

9. Conclusions

This dissertation proposes a novel approach to identify and evaluate the possible fields of application of a product by semi-automatically analysing related documentary sources. The aim is to facilitate technology transfer between academia and industry. In a very synthetic overview, the method consists of two main steps. In Information retrieval (phase 1) document sources are collected and analysed, using dependency patterns, identifying product Functions, application fields and requirements. In the Business evaluation (phase 2), the application fields and requirements are assessed on the basis of Market potential, by interviewing experts in the field, and Economic potential, by extracting costs and revenues of similar technologies from patents and balance sheets.

The application of the proposed method to real case studies addressed by the candidate during the PhD period and in collaboration with the TTO allowed to exemplify the application of the method and discuss its main advantages and implications on technology transfer activities. The case studies considered were selected on the basis of their heterogeneity (heating of carbon nanotube yarns, coating of textiles with water-repellent properties by means of SOL-GEL, photocatalytic ceramic foams for the removal of micro pollutants, industrial dishwashers and wind turbines) and involved different professional figures (academia professors, TTO technical-administrative staff and entrepreneurs).

In conclusion, the application of the proposed method provided the following results:

- Analysing a larger number of documentary sources, even in the order of thousands of documents, compared to common databases such as those of biomimicry, and requiring no prior formatting.
- The documents collected, simply by means of very simple search queries, do not need to be pre-checked and manually filtered by a subject matter expert as the method has proven to be able to discriminate the information needed without running into false positives.
- The effectiveness of Information retrieval by the proposed method, especially thanks to the use of dependency patterns, was quite high if compared to other automatic Information retrieval methods, such as those based on SAO triads. This is valid both for the extraction of Functions and application fields.

- The involvement of the expert in the evaluation of the Market potential is objectified, since the requirements on which his/her evaluation is based are pre-determined thanks to the semi-automatic extraction due to semantic rules.
- The integration of economic considerations in the assessment of technology transfer allows for a broader evaluation of the product than just the technical considerations that typically emerge from the interview with professors. This broadened perspective was in fact particularly appreciated during the interviews with entrepreneurs.

The use of the proposed method proved useful for technology transfer in several ways. In fact, the information gathered proved to be useful in writing the patent for the product in question, both with a view to enhancing it by adding new fields of application and advantages, and to circumventing the patent by being able to discriminate between operating modes and unknown fields of application. Similarly, the same information has proved useful when writing projects to participate in funding calls. Finally, by exploiting such information, even the meeting to present the product to the entrepreneur may be raised to another level, more aware of the strategic aspects and the potential of the product to be leveraged.

All the advantages of the method that have been tested must be read in the light of its main limitations. The method was tested on a few case studies which, although heterogeneous, did not allow for the exploration of many possible areas of research and technology transfer, such as energy plants or products consisting of a large number of components. Overall, few of the people involved come from industry and few of them have any real experience in launching and marketing successful innovative products. The method was always applied by the candidate, who also developed it and knows it well. All the case studies presented correspond to successful cases, where each step was carried out exactly as planned, from the first interview with the proposer to the final economic evaluation.

In addition, several other limitations concern the characteristics of the method itself, which to date is unable to process particularly long sentences, to compare more than two competing technologies, to analyse raw ideas and products at an early stage of development, with little supporting literature.

To overcome these limitations, some future developments of the method have been planned and already started. These include the extension and customisation of the dependency patterns for more specific fields of application, such as the circular economy, the search for other evaluation indexes to accompany the Market potential, especially for products in the very early stages of development, and the extension of the case studies to identify new limitations and peculiarities typical of the proposed method.

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