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BIBLIOMETRIC ANALYSIS APPLIED TO TECHNOLOGICAL PROSPECTING

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ABSTRACT

Academic researchers have contributed to the field of future studies, and this knowledge has been improved through real application in companies and public institutions. Business executives and public administrators permanently face difficult decision processes. Therefore, they must deal with decision context assessment and the potential outcome of the available decision alternatives. Making a decision implies dealing with uncertainties and, in those cases in which the decision focus is technology, prospecting typically presents uncertainties. The aim of this study is to research the application of bibliometric analysis to technological prospecting. This objective is based on two elements that are now available, but that did not exist in the past: (1) internet-based scientific databases and (2) new research studies that employ bibliometric technique to explore the availability of such databases. This study focuses on heating, ventilation and air-conditioning based on geothermal heat pumps as the technology prospecting problem.

Key-words: Technology prospecting. Decision-making. Bibliometrics. Bibliometric analysis.

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ANÁLISE BIBLIOMÉTRICA:
UM ESTUDO APLICADO À PREVISÃO TECNOLÓGICA

RESUMO

Os pesquisadores acadêmicos têm desenvolvido contribuições no campo dos estudos do futuro, e este conhecimento tem evoluído por meio da sua aplicação no ambiente de empresas e instituições públicas. Gestores de empresas e de instituições públicas são permanentemente colocados diante de desafios de decisão, e como tal têm necessidades de avaliação correta do contexto da decisão e dos possíveis resultados que se apresentam como consequências desta decisão. A tomada de decisão implica em avaliar incertezas e, no caso de contextos onde a decisão gira em torno de prospecção tecnológica, as incertezas aumentam. Nesta pesquisa, objetiva-se estudar a aplicação da ferramenta bibliométrica para prospecção tecnológica. A motivação é justificada pela existência de dois componentes importantes: (1) bases de dados eletrônicas via internet e (2) pesquisas mais recentes sobre a técnica bibliométrica, desenvolvidas justamente pela atual disponibilidade das bases de dados. O estudo é focado na tecnologia de climatização de ambientes via bombas de calor geotérmicas como objetivo da prospecção tecnológica.

Palavras-chave: Prospecção tecnológica. Tomada de decisões. Bibliometria. Análise bibliométrica.

1 INTRODUCTION

Technology forecasting is one of the many corporate and governmental challenges. The need to prospect, assess and determine technological pathways aims at improving the decision-making process. The context of an organization or even of a group responsible for governing is complex and derives largely from the uncertainties inherent to decision-making. Reducing uncertainties aims to provide a better understanding of which consequences might result from each decision alternative. The chance of uncertainty not being entirely reduced is often great, but a decision must be reached, nevertheless. This situation is common in technology prospecting cases, as technology development cycles are typically long.

1.1 OBJECTIVE

The aim of this study is to examine the appropriateness of bibliometric analysis for prospecting technologies that are at an early stage, given the natural relation between the challenge of the activity of identifying emerging technologies and the decisions that must be taken regarding research and development (R&D) investments. It is an exploratory study based on bibliographic research, in which the author sought narratives of and cases about the use of the method chosen to prospect technologies in their early stage.

Based on these application cases, the author then attempts to use the method in a particular approach, applying it to a prospecting situation. The method enables an analysis of the history of the publications available to date. Keeping in mind that the technology is in its early stages of commercial use, one can assume that it could have been monitored in advance with a prospecting method.

1.2 RESEARCH ISSUE

R&D investments may or may not yield positive results for companies and public institutions. Therefore, the process involves inherent risk. Part of the risk is due to uncertainties as to which technologies will actually become mainstream in the future. Among the forms of prospecting that have been gaining room lately, bibliometry (or bibliometric analysis) has gained popularity

and is now used more often than in the past. The research problem proposed in this study is whether using bibliometry is appropriate for the prospecting of the technology elected for monitoring in this study.

1.3 REASON FOR THIS RESEARCH STUDY

In the past, the effort to undertake bibliometric monitoring was great, as there were no computer resources nor electronic databases in which to conduct one's search efficiently.

Today, however, this has changed entirely, as the databases of scientific publications are available on the web. Many of them also offer search capabilities that allow one to obtain sufficient quantitative results to conduct bibliometric tracking. Coates et al (2001) argue that the use of bibliometry will tend to grow, as the tools now available will tend to induce one to use this method.

The application of bibliometry is particularly appealing when it comes to prospecting emerging technologies, where different development paths and combinations of these paths compete for use in the future. At present, the key challenge is to make effective use of what is available on the web and bibliometry, together with other information available on the internet, may prove to be an interesting combination to further this process.

For the purposes of definition, the concept of bibliometry (or bibliometric analysis) in this study refers to counting the publications or citations found in scientific and academic databases (Coates et al, 2001).

The tracking of what is published in these databases, when guided by the use of key words, may point to a propensity toward evolution of a given technology. This process would therefore allow one to assess prospectively the pathways that the technology is likely to follow and thereby reduce the degree of uncertainty involved in the investment decisions that are being analyzed.

1.4 LIMITATIONS, RESTRICTIONS AND NECESSARY MEASURES

Because one is deaing with a method based on tracking terms in databases, there are certain limitations, which demand that the user be careful in some ways when employing it.

The first factor requiring attention is the choice of database. Not all R&D information is available on databases about patents or publications. Many are not communicated, for confidentiality reasons. The broadness of the database regarding the subject at hand is also important and it may be necessary to combine research into several databases to reach a fuller set of sources. This notwithstanding, the content of the SCOPUS and WoS (*Web of Sciences*) bases tend to produce very similar results, with high correlation (R^2 close to 0.99) of the results of the two databases, as Archambault et al (2009) showed.

Another limitation concerns how to determine the terms that are to be tracked. First, one should prepare a list of all the terms that might bear some relation with the technology that is being studied, without necessarily hierarchizing their relevance. Second, it is advisable to establish a hierarchy, of the classes and subclasses type, as Woon and Madnick (2009) described. This enables the establishment of relevance trees among the terms as well as an order for searching the terms in the database, from the higher hierarchy to the lower ones.

It is also highly advisable that the terms be validated by experts in the technology that is being studied, without, however, allowing any biases to be introduced by the said experts. One should keep in mind that bibliometry is a methodology that can be bias-free, provided one puts in place anti-bias measures; otherwise, its value-adding ability will fall. In the current study, the technology tracked and the terms for searching it were not validated by experts, but were based on the bibliography.

A third source of difficulty is language. Terms and words are interchanged and may often refer to the same thing. The researcher, to avoid problems connected with the significance of terms, must employ techniques such as stemming – the elimination of the suffixes of words with a common origin, such as plurals and verb tenses. The technique also assumes replacing derived terms by an equivalent term (Glenisson et al., 2005). Furthermore, one can use word significance and similarity techniques to identify terms that refer to the components of a given technology.

Vidican, Woon and Madnick (2009) present other sources of problems in their study about photovoltaic cells:

- ✓ False positive / false negative: the terms determined for tracking do not always represent what one expects them to in all publications.
- ✓ Inconsistency of database coverage: this can be due to how one has determined which sources are to be explored or to the very choice of the databases that are to be tracked. Some choices may cause biases in the bases chosen for the search and even if the method is bias-free, nothing ensures the absence of biases in earlier stages.
- ✓ Lack of search tools in the databases consulted: some enable fairly flexible searching. However, not all of them have anything beyond the basic tools.

A typical bibliometry limitation is the time elapsed between the actual R&D study and its publication, a period often long enough to give rise to doubts.

The research methodology used also helps to generate limitations regarding the study's conclusions. Because of the exploratory nature of such studies, the author is not attempting to confirm a hypothesis, but rather to evaluate the appropriateness of using the method for the intended end. A confirmatory study may be proposed for future research.

One should stress, additionally, that nothing guarantees the success of the technology monitored in this study, given that it is not aiming to assess this technology's propensity to commercial success, focusing instead on the evaluation of the prospecting method, with emphasis on how its use might indicate that the technological pathway followed might be a candidate for evolution until it reaches the commercial availability stage.

These limitations are inherent features of research that relies on bibliometry. One should add that the research context defines most but not necessarily all the care that the researcher should take. Therefore, there might be restrictions other than those discussed here.

2 BIBLIOGRAPHIC REVIEW

2.1 BIBLIOMETRIC ANALYSIS

As per the definition already mentioned, a bibliometric analysis is in essence a methodology to count bibliographic content. Therefore, the method is

not based on an analysis of the content of publications, its focus being only the number of times that the respective terms appear in publications or the number of publications that contain the terms that are being tracked.

This technique can help the decision-making process, in that it allows one to explore, organize and analyze a large mass of data that, without a structured method of evaluation, would not yield such valuable results as regards decision-making (Daim et al., 2008).

Bibliometry can be used to aid other prospecting methods, such as those that resort to scenarios, the aim of which is to study possible future contexts. The scenario method does not try to find a certain forecast of what the future will turn out to be, but only to add further information, improve this information and thus understand the decisions involved better, so that decisions can be made taking into account what has been prospected in order to achieve future objectives (Wright and Spers, 2006).

Identifying the number of times a term is found presumably indicates the level of research activity on theme (Vidican, Woon and Madnick, 2009; Porter, A., 2007).

An analysis of the full content of the publications may result in the number of times that that the terms appear in the respective documents. What the present study does is to count the publications that contain the terms, a simplified approach.

Bibliometric analysis looks for patterns or explanations for unstructured behaviors (Daim et al; 2005). According to these authors, the typical applications concern tracking research trends, identifying emerging areas in basic sciences or identifying how often certain publications are cited.

Bibliometric research can be used to track publications, words, citations, cited references, co-citations, phrases and authorships. Alan Porter (2007) emphasizes that besides the actual counting, the connections between the themes tracked or among authors or institutions may provide indications about the evolution of developments and innovations that are still at an early stage.

Technologies in their early stages may fail to evolve and can end up being abandoned. The challenge of forecasting is assessing the likelihood of this happening or not. Typically, those technologies that stand out have an S-shaped curve.

In some prospecting studies, the authors try to compare the results of the methodology employed for forecasting with other methods. This may enhance assurance regarding the study under way, although it may also give rise to added difficulties, such as requiring a longer time for the study and being more expensive.

Daim et al. (2005), for instance, used the Fisher-Pry model to evaluate the technologies of fuel cells and food safety. They compared the results from the Fisher-Pry model with a maturity curve obtained via Delphi research conducted with experts.

Bibliometric analysis has certain similarities with the TRIZ methodology of innovation management for innovation purposes (Zlotin and Zusman; 1999), developed and improved by Genrich Altshuller, who used this method to identify possible innovation trends.

As in bibliometry, the starting point was a database, in this case of patents, which are classified by types, levels and patterns of innovation. The author advocated that by turning to the similarity among the cases and problems studied, plus a comparison of these with others already solved through a certain pattern of solution, one could estimate that the solution would be developed using similar mechanisms to those identified in these earlier solutions.

Altshuller worked mainly on content analysis, because to decide upon a possible pathway for the innovation being studied, his method required an assessment of the nature of the problem. In bibliometry, one does not necessarily conduct any content analysis, although there are studies in which the tracking of the entire content of publications is used. A broader overview aims to quantify the number of occurrences of the terms within the texts, to eventually calculate the semantic distance between them.

The semantic distance between the terms or words can be measured by their frequence in a group of articles and publications. One of the indicators that can be used to calculate the semantic distance between two terms is asymmetric distance, a method currently used in prospecting studies that rely on web sites. The Normalized Google Distance (NGD) is an indicator that illustrates this well and it is given by the following formula (Woon and Madnick, 2009):

$$NGD\ (t1, t2) = \frac{\max \{\log n1, \log n2\} - \log n1,2}{\log N - \min \{\log n1, \log n2\}}$$

where: t1 and t2 are the terms being tracked; n1 and n2 referes to the number of occurrences of each term individually; n1,2 is the occurrence of the terms jointly and, finally, N is the total number of documents researched. In this study, no attempt will be made to calculate NGD. However, it is an asymmetric distance indicator. The asymmetric distance between one term and the next helps one to set up the hierarchy of terms. In their article, Woon and Madnick (2009) show that the NGDF indicator is directional, i.e., for two terms chosen, the order in which they are placed in the formula influences the outcome and the lower result implies that the first term (t1) is a subclass of the second one (t2).

A fundamental aspect of bibliometry is generating the terms and words to be tracked and how these components are treated during the development of the research study. It is recommended that the bibliographic research be conducted with reasonable dedication in order for the terms to be determined in such a way as to ensure that they encompass the technology that is being analyzed. Eventual gaps can damage the study, as the terms may be combined to form taxonomies that, at the end, may represent the very technological path that will be taken in the future. Ignoring some of these combinations can lead to wrong decisions.

Taxonomic trees can be generated from high hierarchy terms that contain other terms (sub-classes). In the literature, some algorithms for supporting the function of taxonomy generation are mentioned, such as those of Prim, of Edmond and the genetic algorithm (GA), mentioned by Woon and Madnick (2009). The two latter ones are described in the aforementioned article. In the present study, no taxonomic generator was used, the terms having been chosen based on the literature.

2.2 DECISION-MAKING PROCESSES: ASPECTS OF TECHNOLOGICAL STRATEGY

The study of decision theory is vast and involves many approaches. An in-depth study of this subject is not the focus of the present research. However, there are aspects of the decision-making process that may influence the tracking

and monitoring of emerging technologies, since this latter activity is the outcome of a set of decisions taken previously.

James March (1978) argued that human rationality is conditioned, or bounded. Based on the contributions of Herbert Simon as from the 1950s regarding human rationality, March argues that there are certain behavior "anomalies" in the decision-making process that influence rationality. On the other hand, humans adapt to situations and mold their behavior accordingly. The author advocates that this process creates a behavioral intelligence that might help the decision-making process. These teachings are important for the process of bibliometric tracking, because during the stage of terms determination, or slightly before or after it, experts may be consulted. The interaction between the latter and the researchers can both enrich the process and incorporate into it problems derived from conditioned rationality.

Alan Porter (2007) argues that managers tend to base their decisions on intuition, especially when the issue at hand involves technological management. Using intuition when making decisions has some positive aspects. Khatri and Ng (2000) point out arguments in favor of it. Intuition is fast and bias-free, and represents a rationalizing thought model, although one cannot identify how this mechanism works. This process represents what Said Elbanna (2006) called intuitive synthesis.

The link between this theme and bibliometry can be explained: if the tracked technology is new, one can apply a full list of terms with no hierarchy among them. This at first entirely exploratory approach helps one to obtain preliminary data to provide input for experts regarding an initial decision on the terms that are to be tracked. There is, therefore, a decision to be made at this point, and to make use of the experts' experience in the use of their intuition, a preliminary bibliometric result can be highly valuable.

The Prospect Theory of Kahneman and Tversky (1979) provides arguments that indicate that humans are more averse to risks linked to gains than to losses. This tendency might influence the decision-making process that relies on bibliometric tracking results.

The choice of terms may contain biases derived from this risk aversion asymmetry. Managers at established companies may disregard terms that refer

to technological breakthroughs, whereas managers at new firms may overvalue them. Part of these problems can be mitigated by using bibliometry in a balanced and careful manner, to avoid the interference of human nature in the face of decision-making situations.

Almeida, Onisuc and Lesca (2007) argue that using the construction of meaning by means of creativity applied to the weak signals contributes to innovation and to the mental model. A combination of the tracking of weak signals with bibliometry might aid decision-making.

Day and Schoemaker (2000) indicate that there are problems in the identification of technological threats for already established companies. According to these authors, there are four potential problems that incumbent firms are subject to in relation to technological issues:

- ✓ Entering research into the new technology late;
- ✓ Attention biased toward that which is familiar;
- ✓ Reluctance to truly commit; and
- ✓ Lack of persistence.

Any of the aforementioned problems involves decisions. Understanding the nature of these decisions during decision-making helps one to apply bibliometry with sufficient care to add value to the decision-making process.

2.3 CLIMATIZATION USING GROUND HEAT PUMPS

The technology chosen for bibliometric tracking is the climatization of environments using ground heat pumps. This is an unconventional air-conditioning system that resorts to a heap pump buried in the ground to absorb or release heat. Conventional air-conditioning systems conduct this heat exchange with the external air or with iced water.

In the technology tracked in this study, heat is extracted from the environment and transferred into the ground by underground tubes that carry the refrigerating liquid or water into the subsoil, where the heat exchange takes place. When the cycle involves heating, the heat is absorbed from the ground and carried by the cooler or water to the surface. A compressor handles the compression cycles and an evaporator conducts the heat exchange with the

ambient air. The ground is the source of energy for heat exchange, thanks to its particular geothermal properties (Hughes et al, 2008).

It is important to stress that the term "geothermal" has a broad meaning and applies to a variety of contexts. The most common one is the term's association with sources of ground heat from volcanic activity. Another meaning concerns the thermal properties of the ground.

The ground's temperature is constant after a certain depth. A study conducted by Swenka (2008) in the state of Iowa in the USA indicated that the ground's temperature stands at some 52ºF (11.1ºC).

Moreover, the ground's temperature pattern converges toward an average value as depth increases. As from 28 feet (8.5 meters) the fluctuation is minimal (Swenka, 2008; http://www.geo4va.vt.edu/A1/A1.htm - University of Virginia). Figure 1 shows the profile of ground temperature as a function of depth.

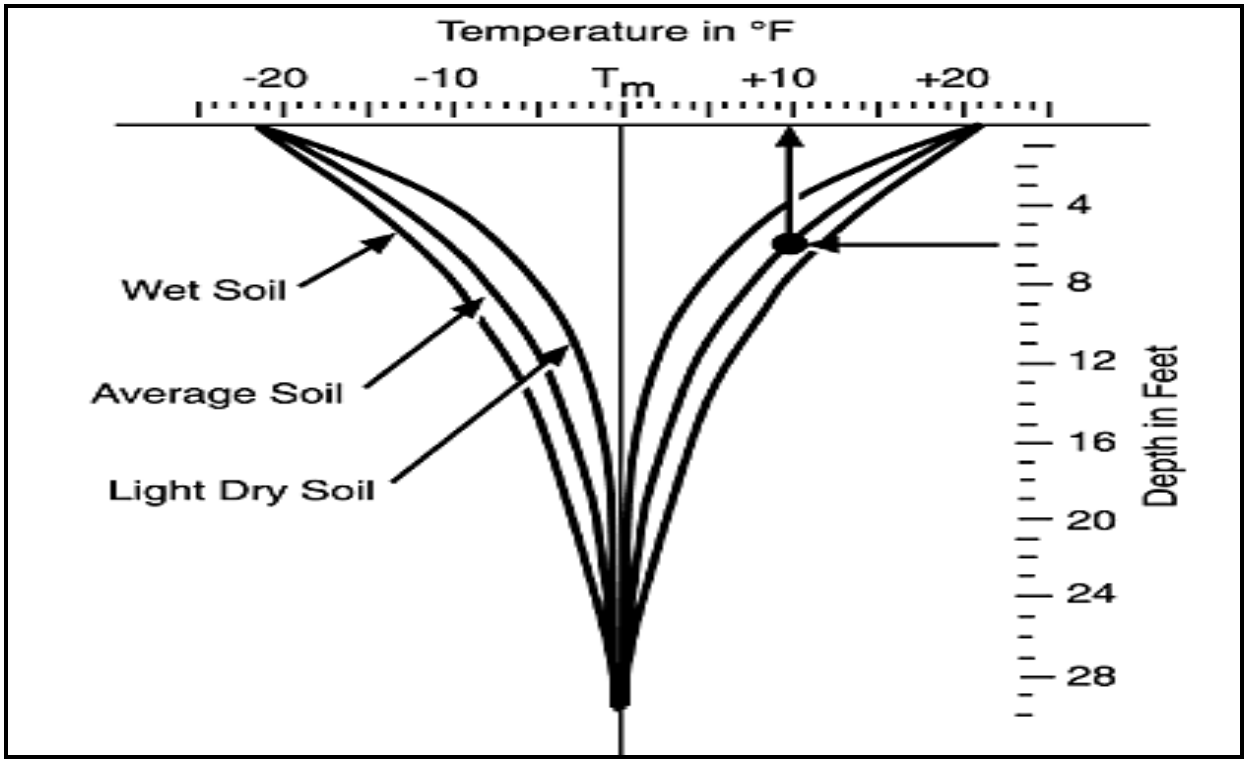


Figure 1: Temperature profile as a function of depth

Source: http://www.geo4va.vt.edu/A1/A1.htm

Fig. 2 shows the temperature fluctuation curve over the course of the year and at different depths. The measurements were taken in the northern hemisphere, where the summer months are July, August and September.

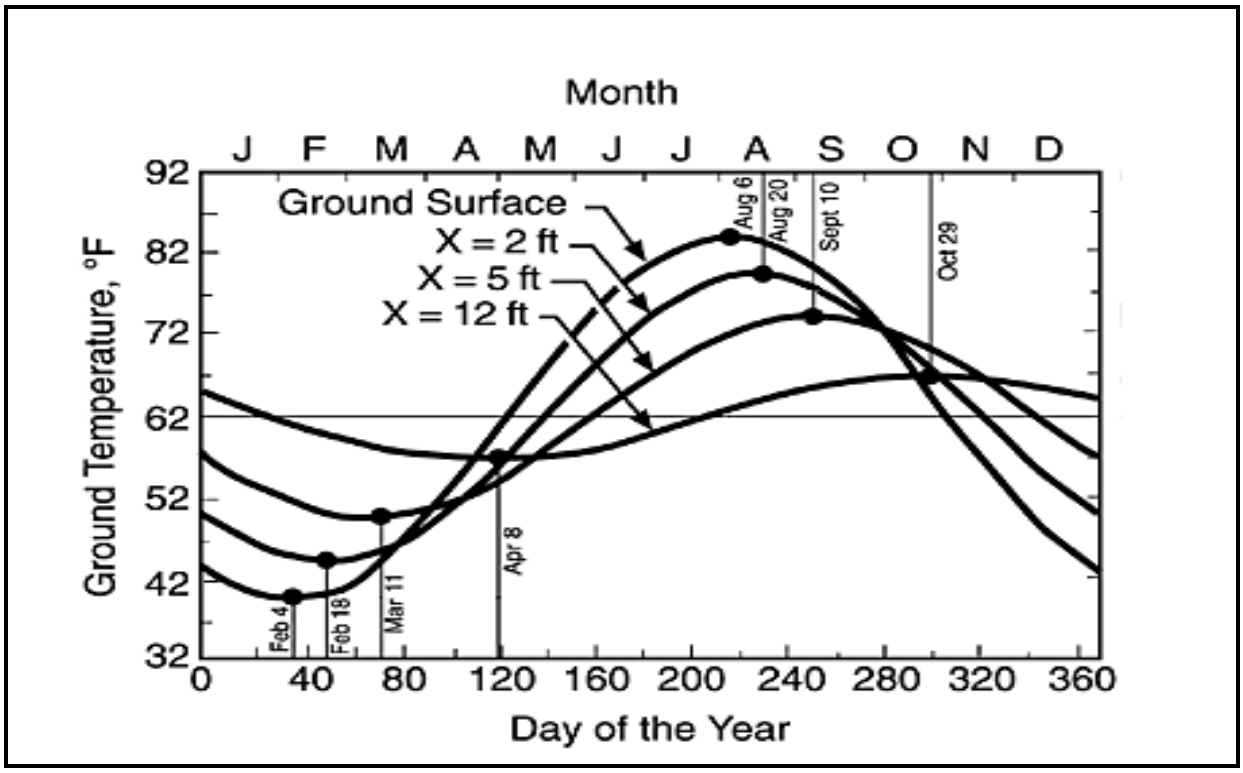


Figure 2: Temperature fluctuation curve

Source: http://www.geo4va.vt.edu/A1/A1.htm

The graphs in Figures 1 and 2 show that ground temperature fluctuates very little after a certain depth regardless of surface temperature. This property of the ground allows one to use a heat pump to exchange heat with the ground. This is the difference between a conventional climatization system and the geothermal systen. As heat exchange is conducted underground, the surface compressor requires no electric energy to exchange heat with external air or with refrigerated water (typically generated by another piece of electrical equipment). Thus, there are natural power consumption savings. In the present study, no attempt is made to assess the system's power savings characteristic as an end per se, but the nature of the energy efficiency is one of the terms searched for in the publications. Other inherent aspects of this technology are described below.

As the heat exchange occurs underground, one can reasonably assume that there is a vertical, horizontal or even diagonal borehole in the system. The heat exchange is conducted by a heat pump, therefore this term is also one of the components of the research. Researchers often mention the ground as a source of energy, which therefore adds the terms energy and heat pump to the list of key words.

Ground water sources are also terms to be researched, as it is unnecessary to bury the heat pump for the system to work – the pump only has to be submerged in water to produce the same heat exchange effect. The list of terms, expressions, phrases and key words below are the starting point for the establishment of a preliminary taxonomy. The terms are in English, this being the language of the publications in SCOPUS. Words used in associated technologies or derived classes of technology were also tracked, but only to validate the relevance of the terms further up the hierarchy. The terms are: energy, ground, water, efficiency, geothermal, HVAC (heating, ventilating, air-conditioning), source, ground source, ground water, GSHP (Ground Source Heat Pump), GHP (Geothermal Heat Pump), air conditioning, heat, heating, cooling, heat pump, loop, exchanger, heat exchanger, seasonal, coupled, borehole, vertical borehole, grout, u-tube, carbon, climate, climate change, carbon dioxide and CO2. Other terms were considered in this study, but proved ineffective in relation to the tracked technology. Certain terms, such as GHP (geothermal heat pump) are used today, but during the initial period of this research study, from 1991 to 2008, it would have been unadvisable to use this expression as a taxonomy root. On the other hand, heat pump is a term that was broadly used even before 1991.

GHP is a technology that is in the early stage of adoption. The Swenka (2008) study conducted in the USA indicated that some people are interested in installing the system in their homes, but lack a clear idea of what the technology actually consists of.

Most of the research on this technology links the geothermal phenomenon with power generation by using the heat from thermal sources of a volcanic nature. This finding led this study rank the term "geothermal" low in the hierarchy of terms (not a root term). The term was adopted as being in a subclass of terms such as "energy," "efficiency" or "heat pump" to try to find results that converge toward using the ground as a heat exchanger for climatization rather than as a source of heat for vaporizing water or powering turbines. No attempt was made to analyze whether the two forms of geothermal energy bear any relation to each other.

It must be stressed that the climatization of environments accounts for quite a large share of the consumption of electric energy. The Brazilian Labeling Program for buildings (PBE) indicates a weight of 40% for the air-conditioning

system (AC) in the classification of a building's efficiency level, while it ascribes a weight of 30% to the lighting system and of 30% to the surfacing of the building (Cruz, 2008).

The technology's current stage is that it is commercially available only in a few countries, but it is a suitable technology for commercial products. However, one must keep in mind what Watts and Porter (1997) emphasized in their study. They argued that the commercial success of a technology depends on countless non-technological elements, such as market, socioeconomic, institutional or regulatory factors.

As was previously mentioned, this study is not designed to assess the propensity toward commercial success of the tracked technology. Furthermore, it is important to stress that what is sought here is merely to evaluate whether bibliometric analysis is appropriate to monitor the future of the technology that is being studied, and nothing else.

3 METHODOLOGY

Exploratory research is used to make discoveries, as it affords the researcher freedom to explore ideas and intuition regarding the phenomenon at hand (Gil, 1987). It has no clear definition of boundaries and allows the researcher greater freedom, because it tries to understand why and how things happen (Castro, 2006). This piece of research conducted two bibliographic studies. The first concerned academic literature on the applications of bibliometric analysis and also included thoughts on decision theory as a means of providing guidance for the research and the use of the bibliometric methodology. The second tracked academic literature to identify the number of publications that contain the key words related with the technology tracked in this research study.

Some of the aspects of decision theory are included in this study to provide guidance on how to use the bibliometric methodology, which, being a means of providing support for decision-making, must be employed in such a way as to reduce process difficulties.

The technology for climatizing environments (heating or cooling) with underground heat pumps is part of a group of renewable energy technologies. This area is tending to produce a large number of emerging technologies that

may become available in the future. However, there are still only a few studies that resort to bibliometry as a prospection methodology in the field of renewable energy (Vidican, Woon and Madnick; 2009).

This study comprises three steps essentially, based on what Ziegler et al (2005) proposed:

- ✓ Bibliographic survey of terms and words related to the technology that is being studied;
- ✓ Identification of the number of academic and scientific publications that contain these related terms and words;
- ✓ Analysis of the results in terms of the growth of the number of publications containing the terms and words, identifying the relation with the greatest growth.

The research of the terms related to the technology was conducted on the SCOPUS publications database. This was chosen for being multidisciplinary, with works ranging from the basic sciences to different types of engineering and even to management and the social sciences. It was considered a good source for the pilot study on renewable energy conducted by Woon, Henschel and Madnick (2009). Words and terms were combined for tracking in this database. This technique is approximately in line with the practices of Kostoff et al (2001) in their study about renewable energy, which resorted to the integrated use of bibliometry and word mining.

In the present study, a search was conducted to find out what was the number of publications that contained the terms or key words connected with the technology in question. No search of the number of occurrences within a given publication was conducted and the search tools used where those available in the SCOPUS website. The data survey was conducted over an extended time span (1991 to 2008, a longitudinal study), with a view to evaluating the number of publications that contained the terms during this period.

One can regard this study as a pilot for future evolution. There are methodologies that might contribute to the research, such as the analysis of the semantic distances between the terms and words (Woon, Henschel and Madnick; 2009). This methodology assumes it is necessary to evaluate the full content of the texts published, which would demand great storage and data processing

capacity. However, one should point out that an analysis of emerging technologies would have to include such methodologies. Therefore, the present study recommends future research to complement the work developed here and to achieve further progress.

4 DATA PRESENTATION AND ANALYSIS

Using the terms surveyed in the bibliography on the studied technology as a starting point, a preliminary identification of the number of publications containing these terms was conducted. The first tracking approach started with the term "heat," given that the fundamental component of the researched technology is heat exchange. With this term as a starting point, the study goes into increasingly great hierarch depth to look for associated terms, or subclasses. Figure 3, below, shows the first structure tracked. The growth rate from year to year (% p.a.) is shown in the graphs. The compound annual growth rate (acc. CAGR) is also shown. Note that the vertical axis of the growth rates is the axis on the right in the graphs.

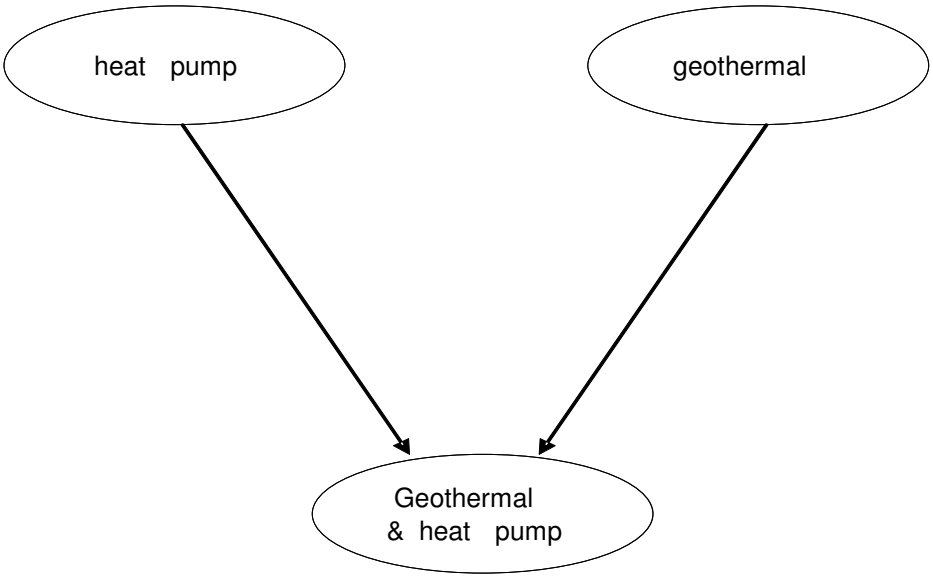
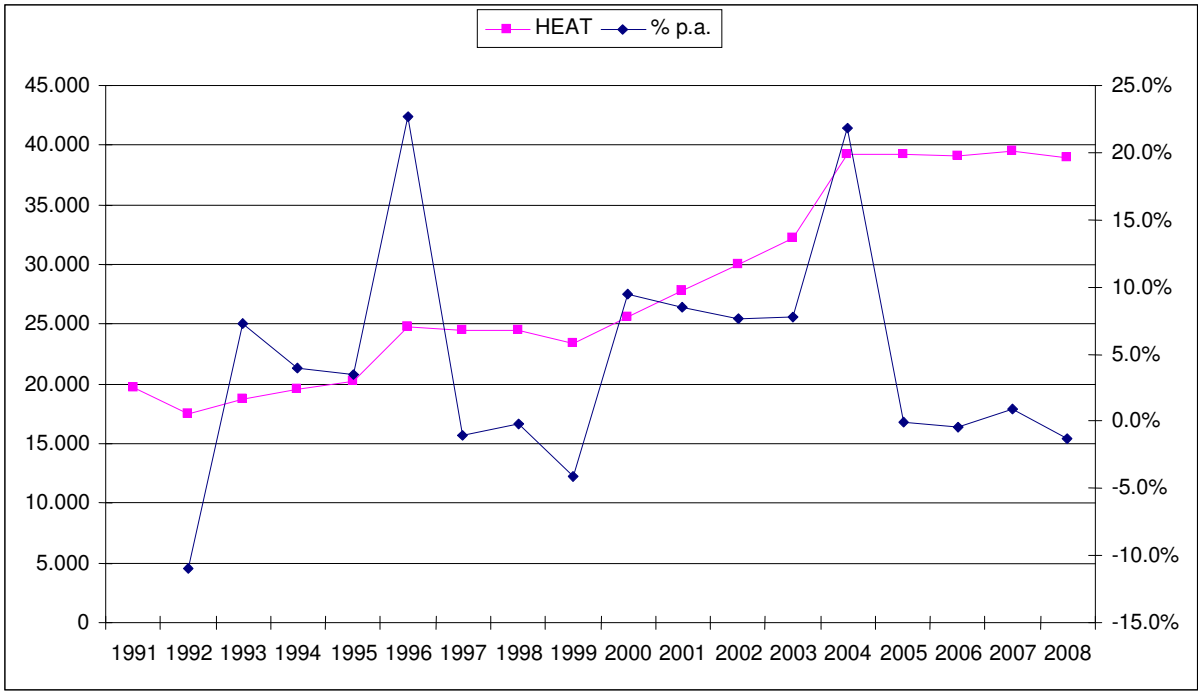


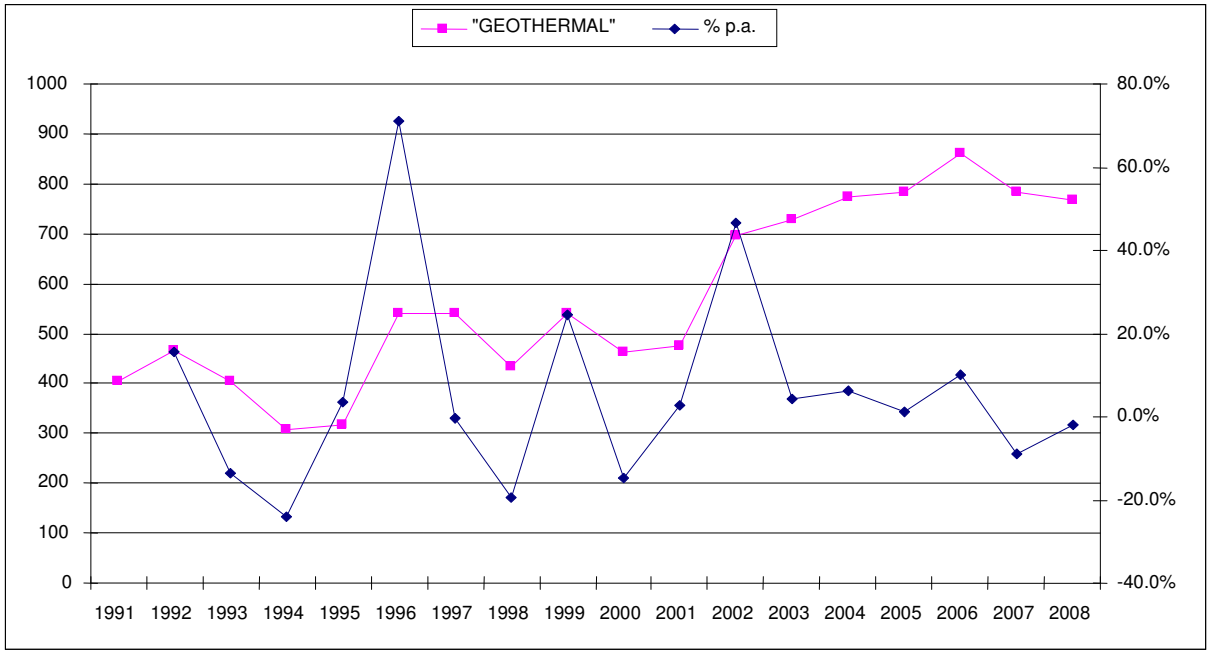
Figure 3
Source: Research study data



Graph 1

Source: Research study data

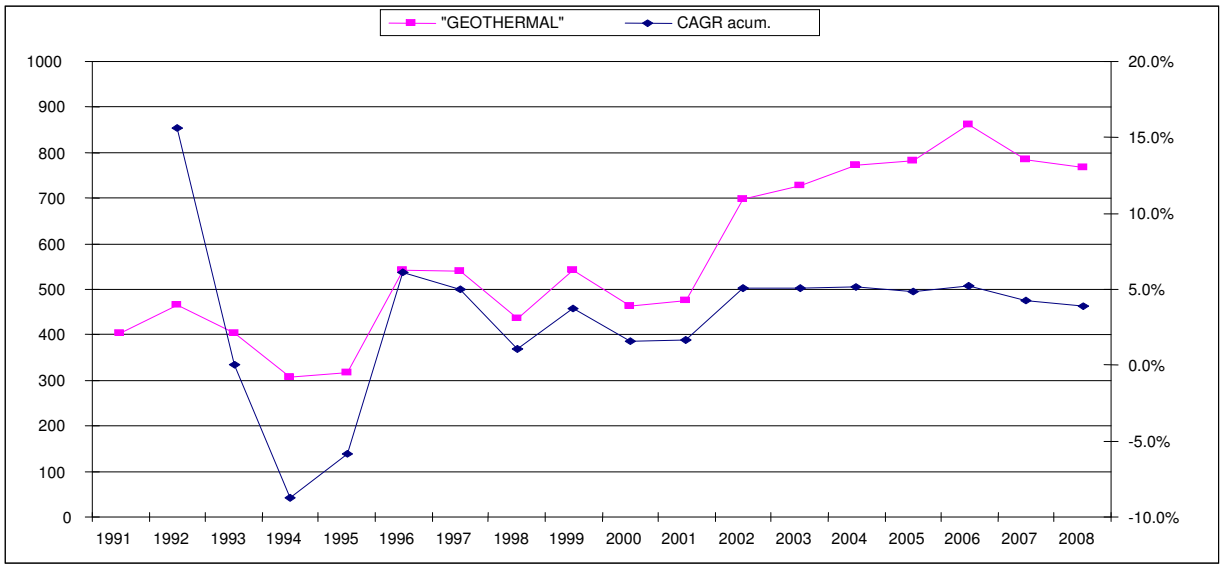
The growth of publications containing the term "heat" does not mean much. Observing the behavior of the term "geothermal," one gets the following (Graph 2):



Graph 2

Source: Research study data

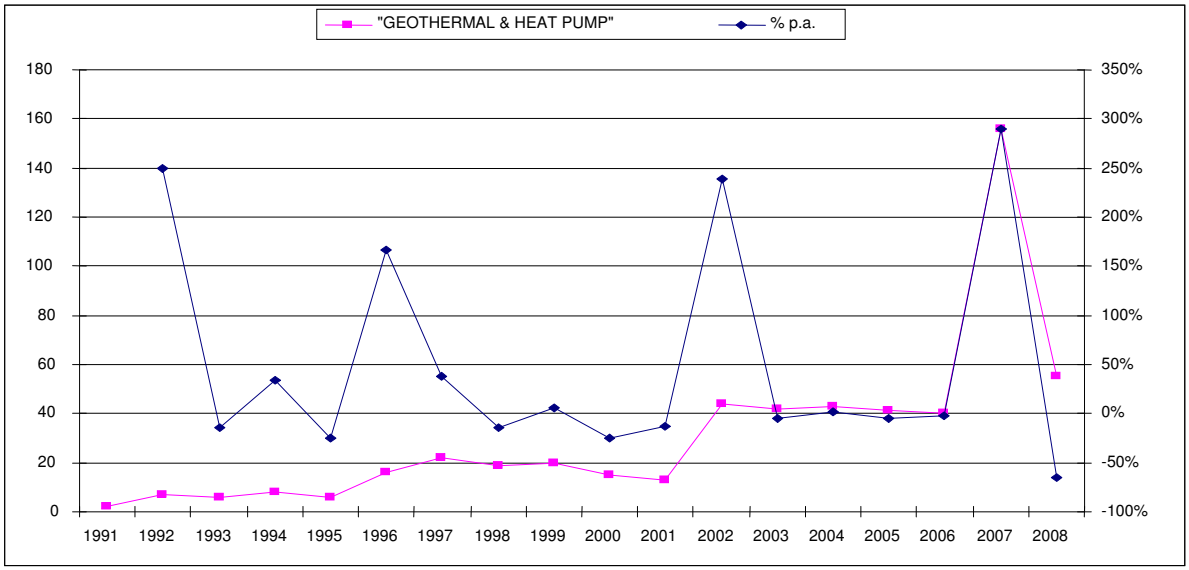
As already mentioned, the term "geothermal" is not regarded as a taxonomic root in this study, because it has broader meanings. On the other hand, one should point out that the average growth rate of the publications containing this term varies greatly in the first four years of the period studied, stabilizing after that at around 4.5%, as shown in Graph 3.



Graph 3

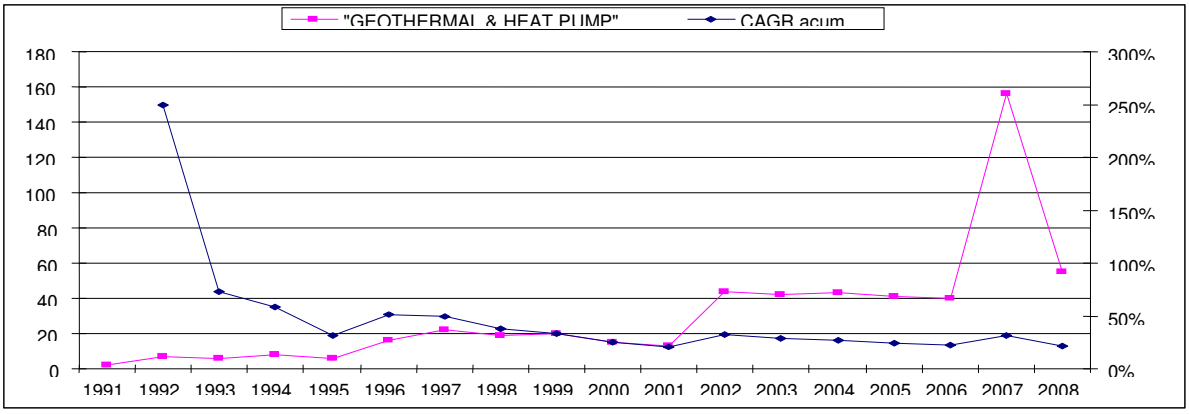
Source: Research study data

The relevant fact appears when one combines in the search the terms "geothermal" and "heat pump," as shown on Graphs 4 and 5.



Graph 4

Source: Research study data



Graph 5

Source: Research study data

The point to be highlighted here is that the average growth rate of the number of publications containing both terms was very high as from the first year of observation and remained at levels five times higher than that of each one of the terms on its own, as Graph 5 shows. This fact, if identified by a structured monitoring process, might indicate that one possible technological pathway would be the geothermal heat pump one.

If the combination of geothermal and heat pump was relatively strong, then it would be interesting to evaluate it using a different path to try to improve the degree of prospecting assurance. For example, the researchers might have thought about evaluating whether "heat pump" would appear with "energy," because in this case the research would be associating both terms. Additionally, following this tree, one might associate the terms "water" and "ground," as they might indicate a submerged heat pump.

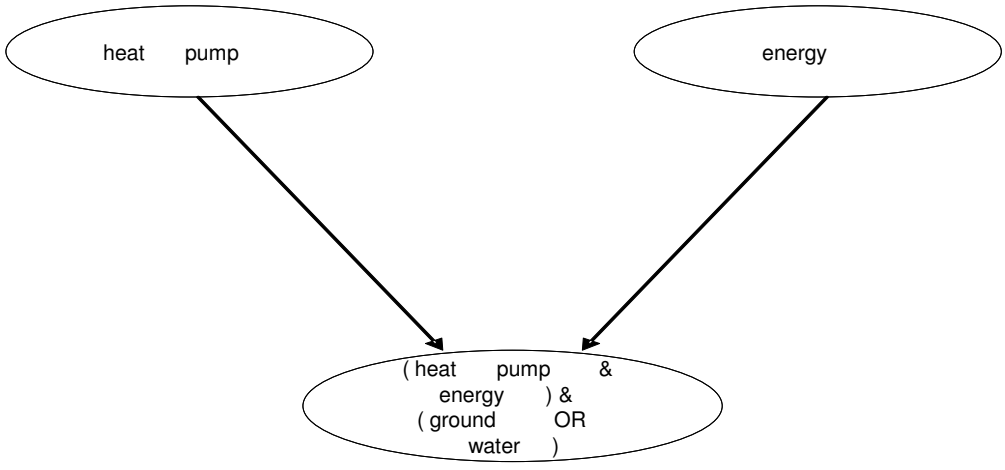
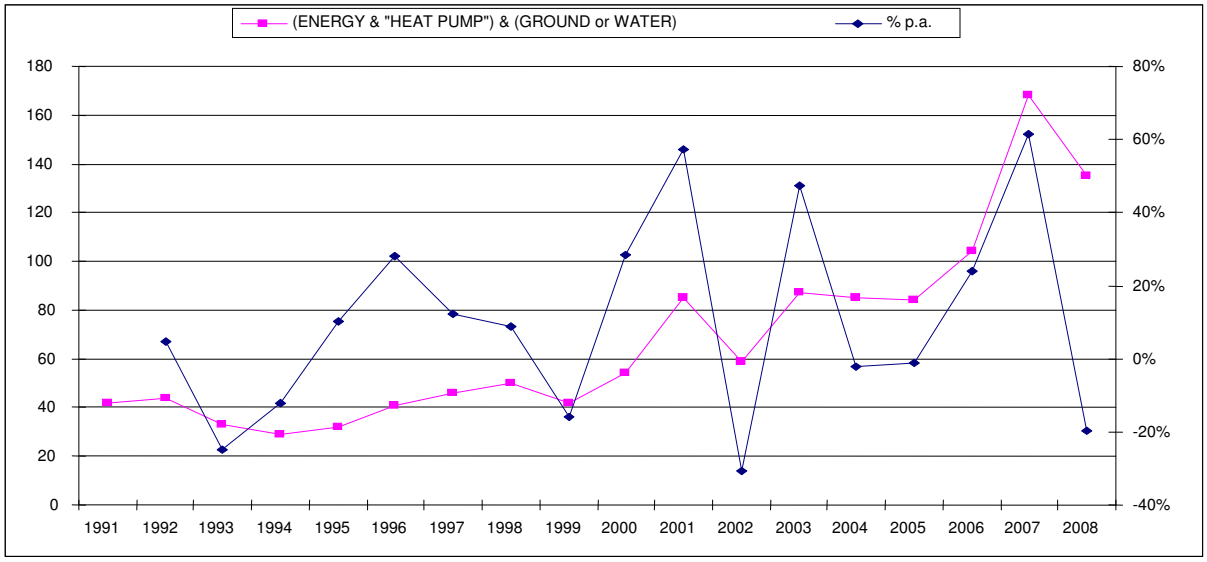


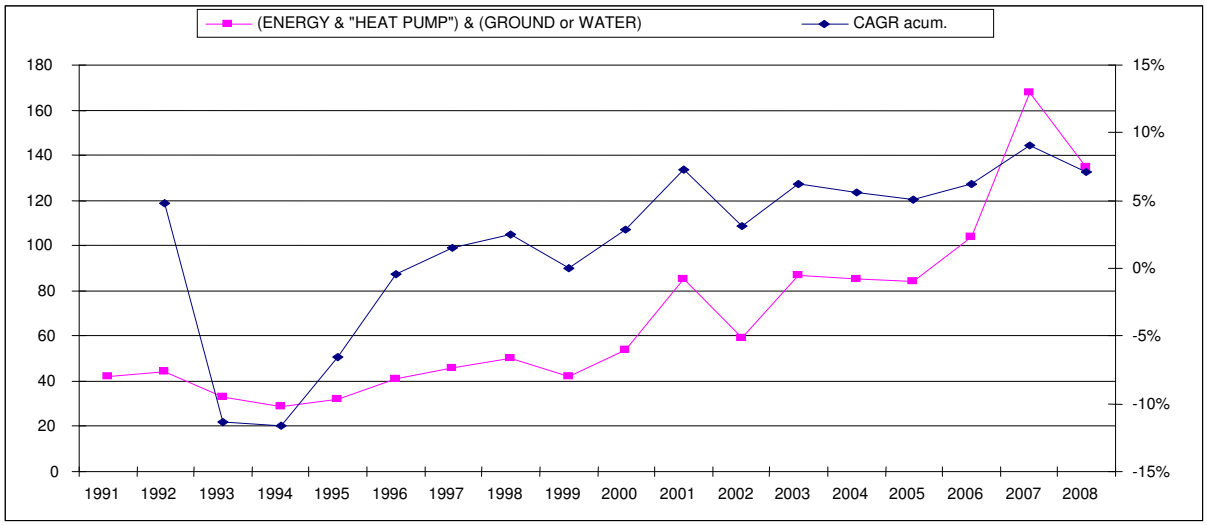
Figure 4

Source: Research study data



Graph 6

Source: Research study data



Graph 7

Source: Research study data Graph 6

Observing Graphs 6 and 7 one sees that the combination of "energy" and "heat pump" with ("ground" or "water") was erratic in the first three years of the period studied, but that it became consolidated thereafter, with a positive compound growth rate. However, this combination might be connected with studies on power generation using heat pumps. Therefore, it would be necessary to combine other terms from lower classes to establish boundaries for the research. In this case, the terms that were added were "HVAC," "air

conditioning," "heating," "cooling" and "ventilating," all of them linked with the connector OR. This set, however, was linked to the initial set with AND. The result is shown in Graphs 8 and 9. Figure 5 shows the tree of terms.

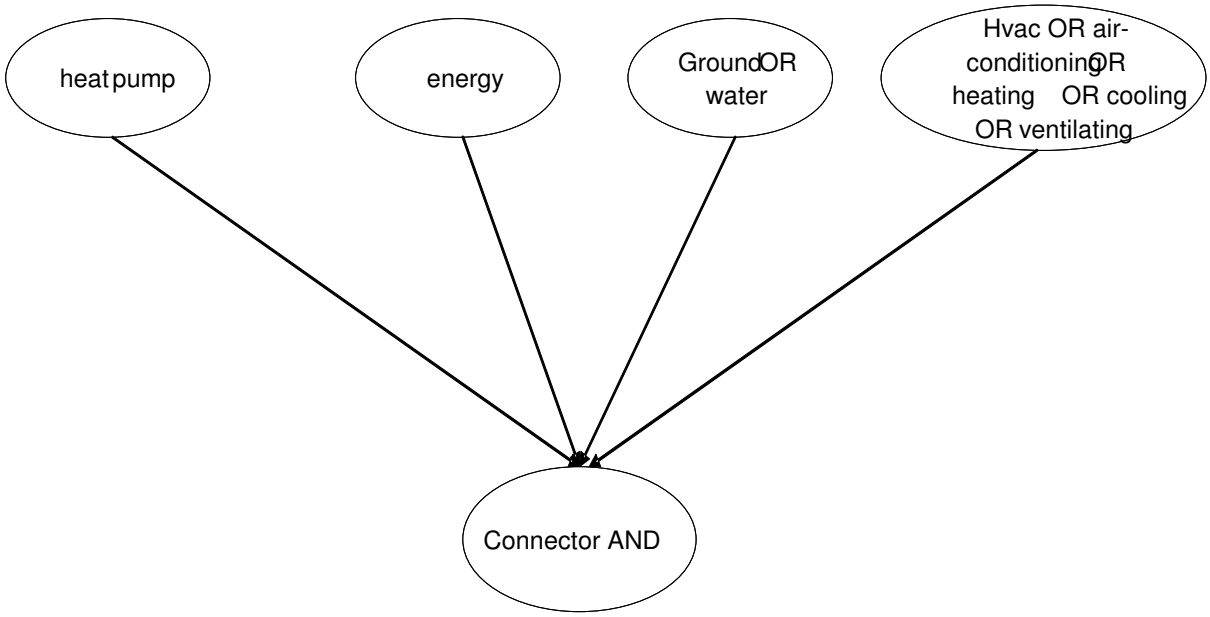
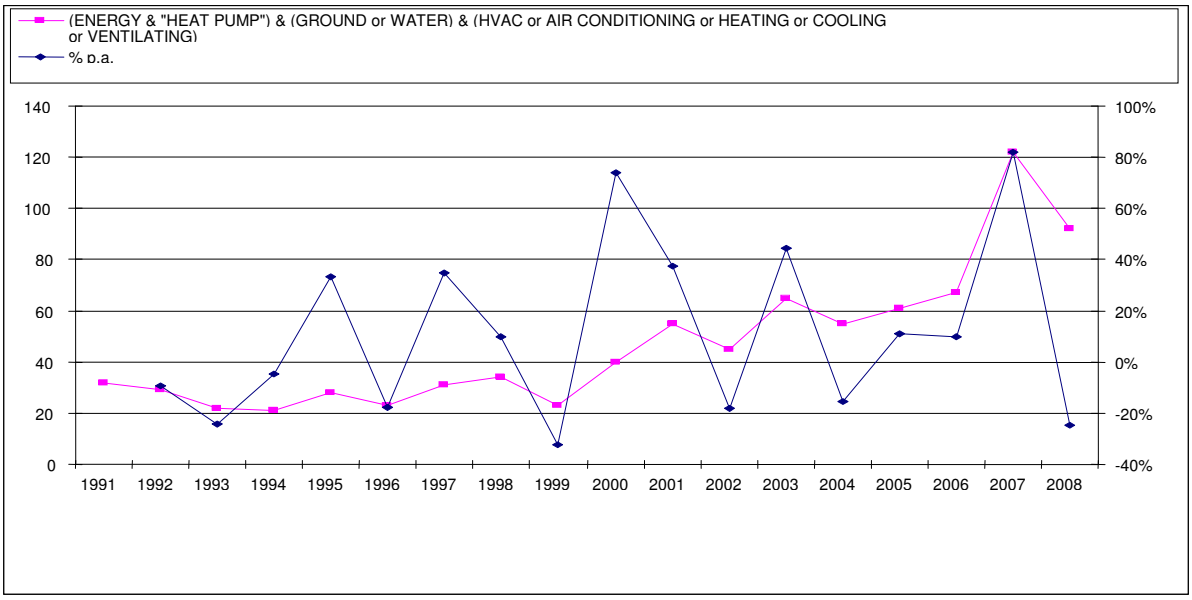


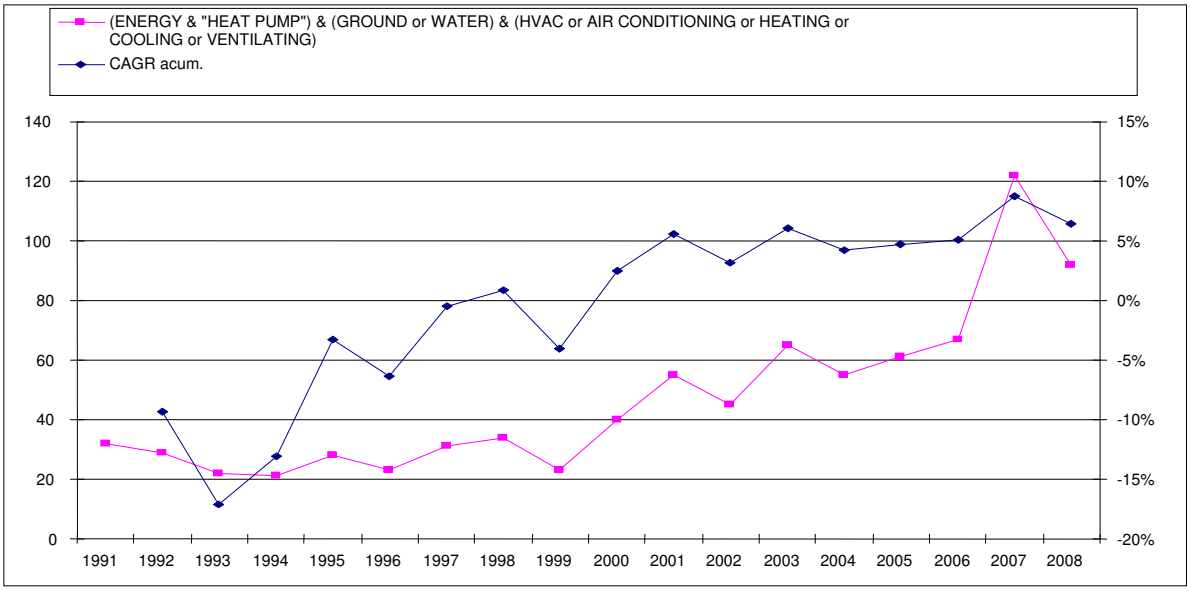
Figure 5

Source: Research study data Graph 6



Graph 8

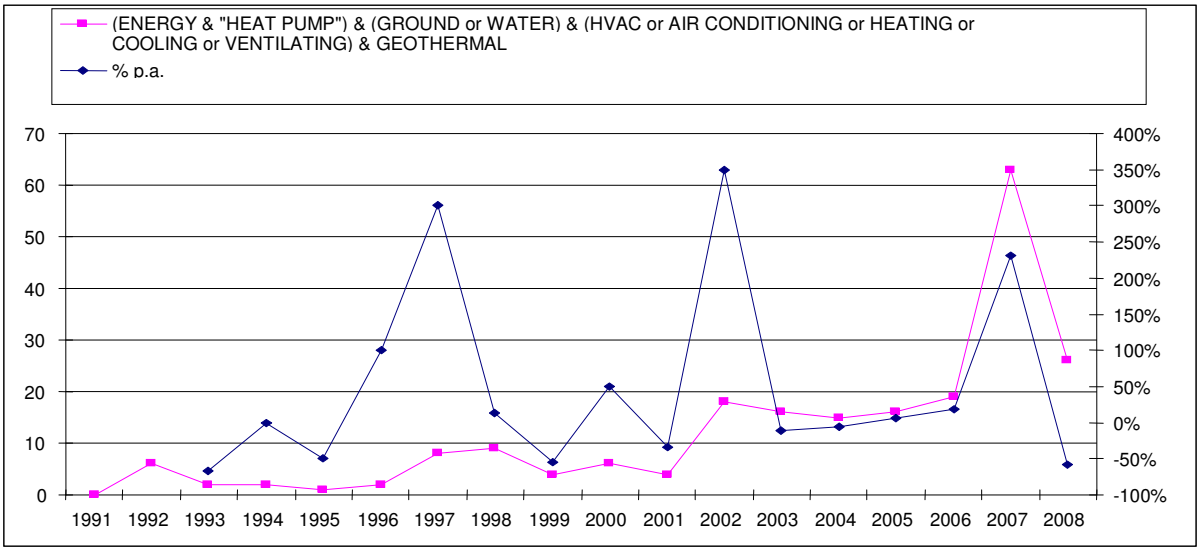
Source: Research study data



Graph 9

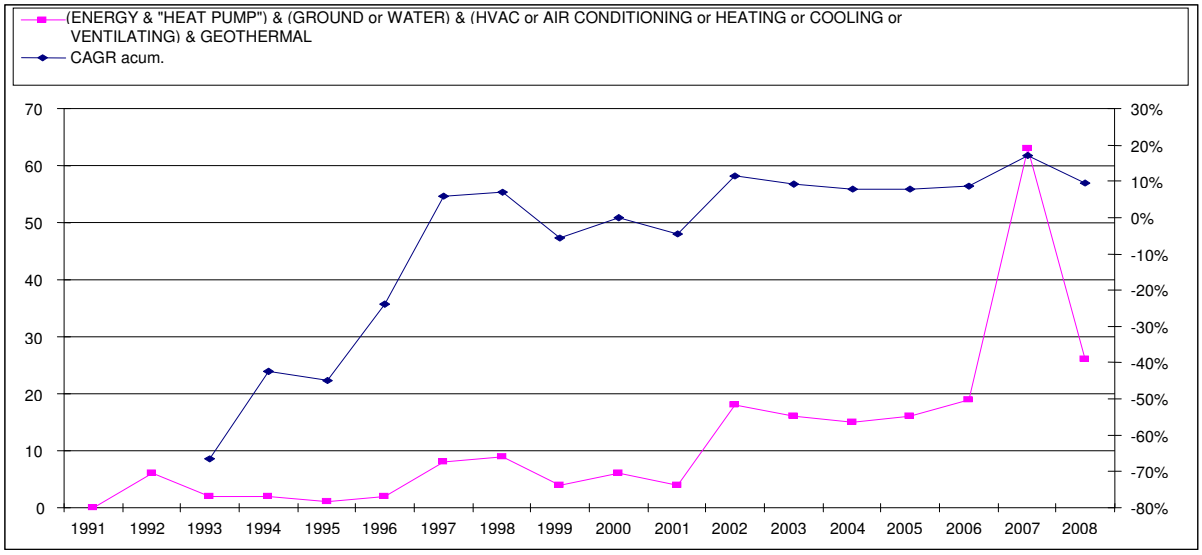
Source: Research study data

A glance over the results of Graphs 8 and 9 would fail to show that the tracked association contained anything of significance in the first five years; however, a growth bias would be seen in the average growth of the number of publications, which might indicate that a development scenario would be a plausible option thereafter. As from the year 2002, the compound annual growth rate was approximately 6%. When one broadens one's attention by adding the term "geothermal" to the tree, the results shown in Graphs 10 and 11 were obtained.



Graph 10

Source: Research study data



Graph 11

Source: Research study data

One can see that in this context, in which the term "geothermal" is associated with the others, the average annual growth rate of publications increases approximately 50% for the period during which the growth of publications was considered relevant, i.e., as from 2002. Assuming that the analysts would be thinking prospectively, it is likely that the publication activity would draw their attention as early as 2002. Exploring matters a little more, one might think about evaluating how research into the thermodynamic properties of the soil was developing, especially concerning those aspects that refer to temperature, soil and depth. What one obtains from this tree (Figure 6) is shown in Graphs 12 and 13.

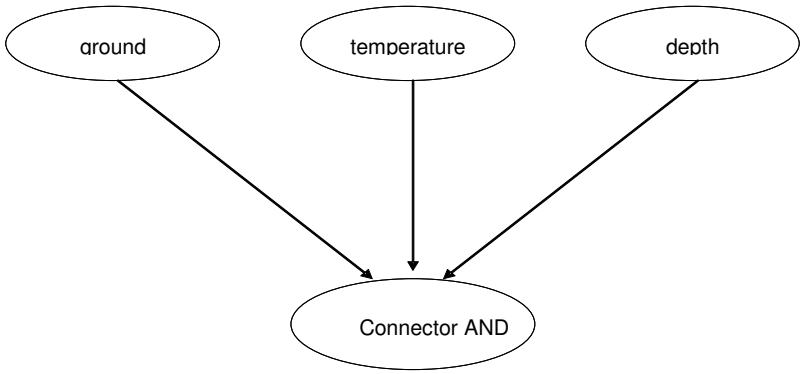
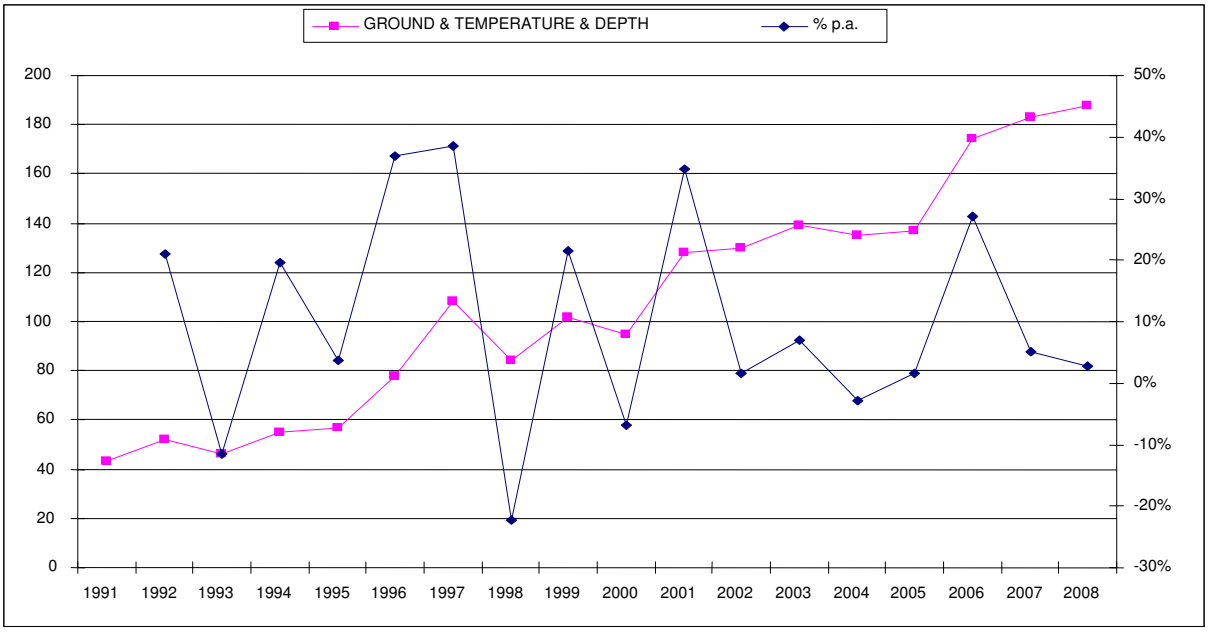


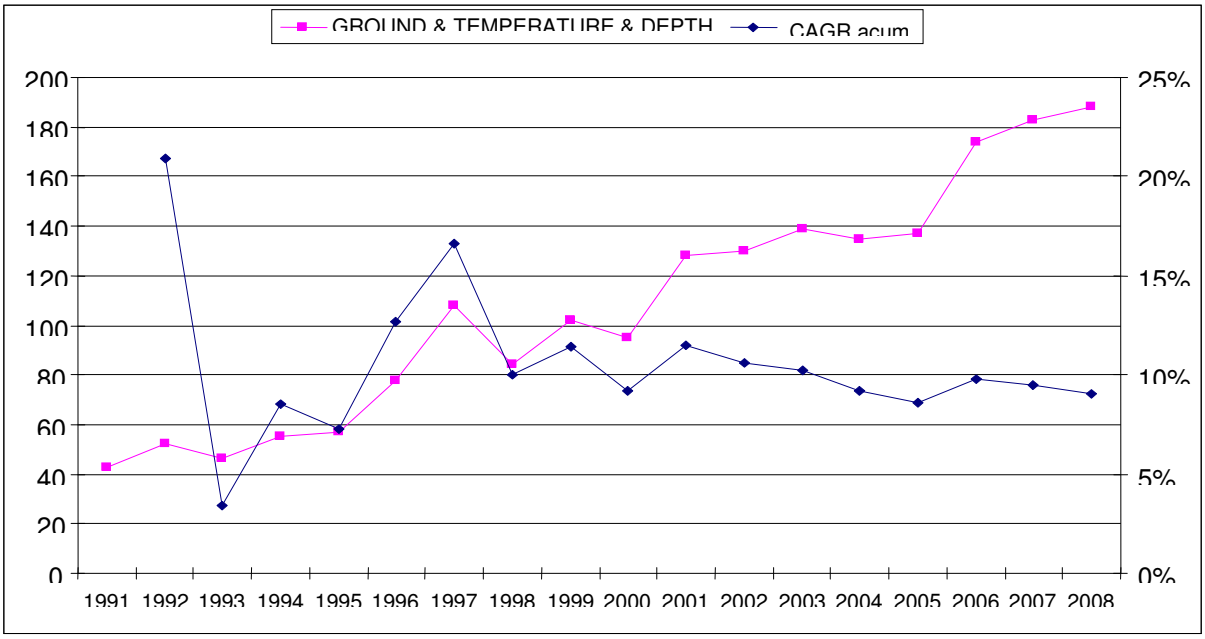
Figure 6

Source: Research study data



Graph 12

Source: Research study data

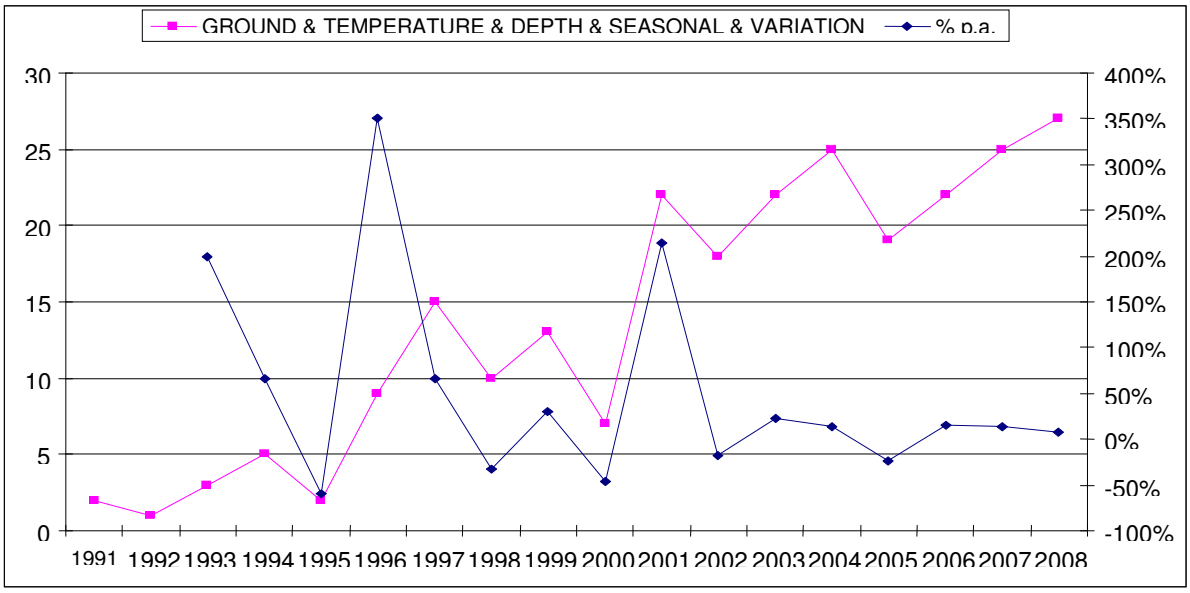


Graph 13

Source: Research study data

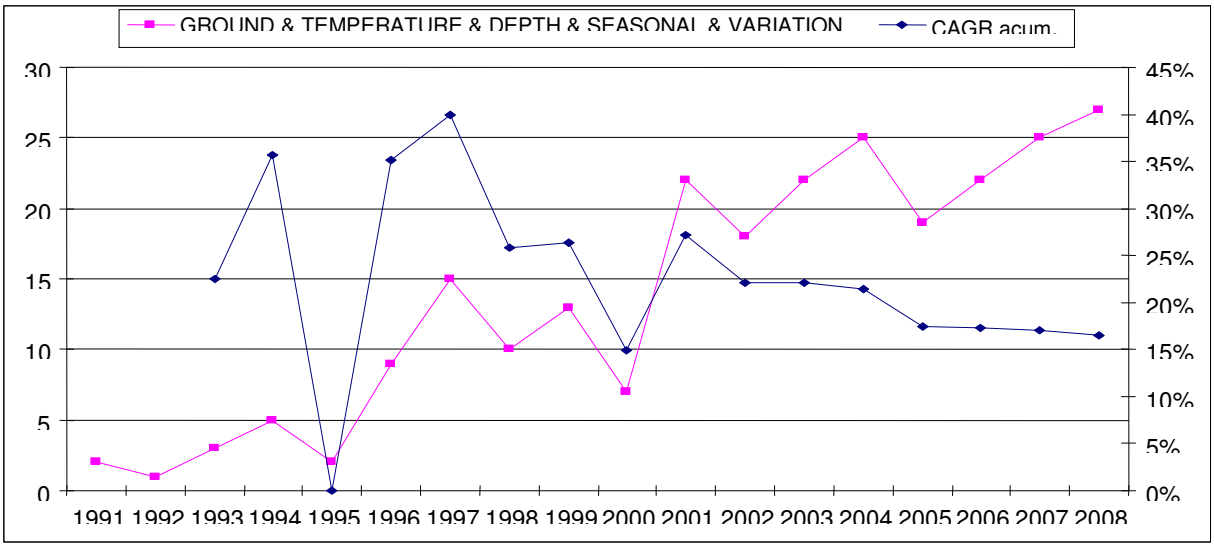
One can observe the growth trend of the number of publications containing this combination. This indicates that the research studies, especially as from the second half of the 1990s, resulted in a growth of publications on average, and at rates close to 9% p.a.

The combination above does not necessarily indicate a propensity to resorting to the ground's property of maintaining a stable temperature according to depth. However, one might think about this propensity if the studies included a seasonal profile of soil temperatures. In other words, if the research studies tried to discover whether the stability of temperature was actually confirmed over a one-year period, throughout the summer and the winter, then this propensity might be confirmed. Therefore, the terms "seasonal" and "variation" were included in the tracking. The results are shown in graphs 14 and 15.



Graph 14

Source: Research study data



Graph 15

Source: Research study data

The average increase in the number of publications containing the terms "seasonal" and "variation" along with the terms "ground," "temperature" and "depth" is far greater than what was observed without the respective terms. This indicates that as from the mid-1990s there was greater interest in studying the thermal properties of the ground, its being plausible to assume that one of the focuses of the research studies was the stability of the temperature over the course of the seasons of the year. In other words, the use of this property of the ground might seem imminent to anyone who might be monitoring the tracked technologies.

Another interesting approach would be to compare the number of publications of the research studies on "heat," "exchanger" and "heat pump" overall with the number of publications that included these terms along with "ground" or "water." The first tracking would identify what has was being researched in general terms, whereas the second would identify the set of these research studies along with "ground" or "water". If the second tracking were growing more, it would indicate a potential new technological pathway. Figure 7 and Graphs 16, 17, 18 and 19 show the results.

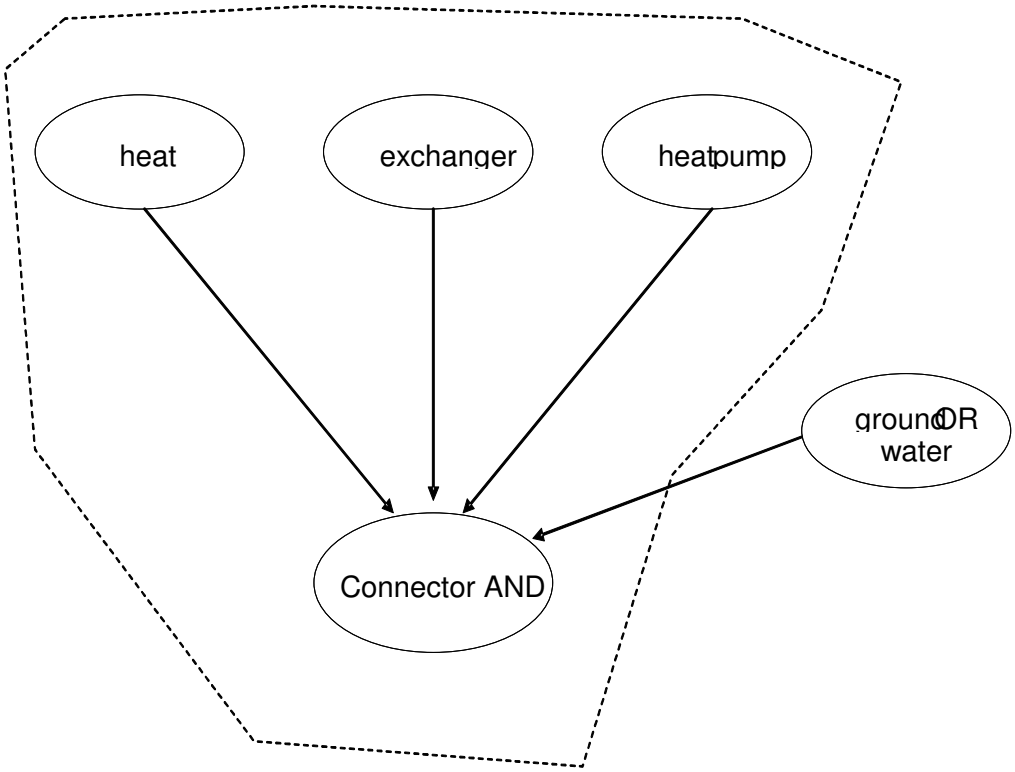
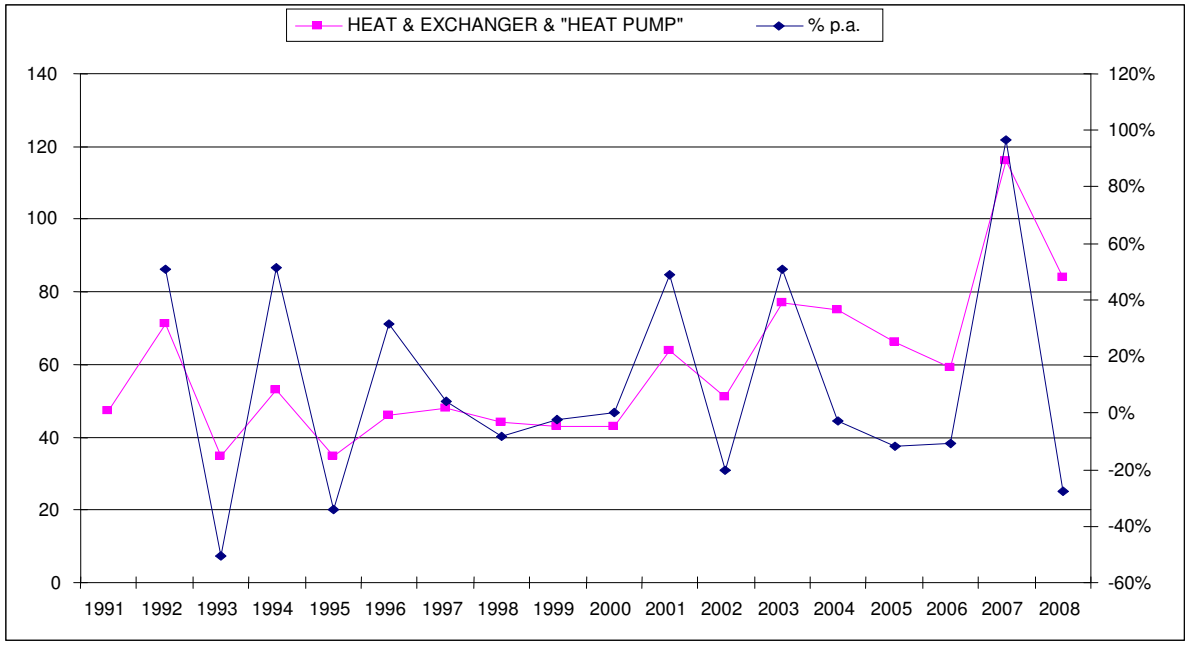


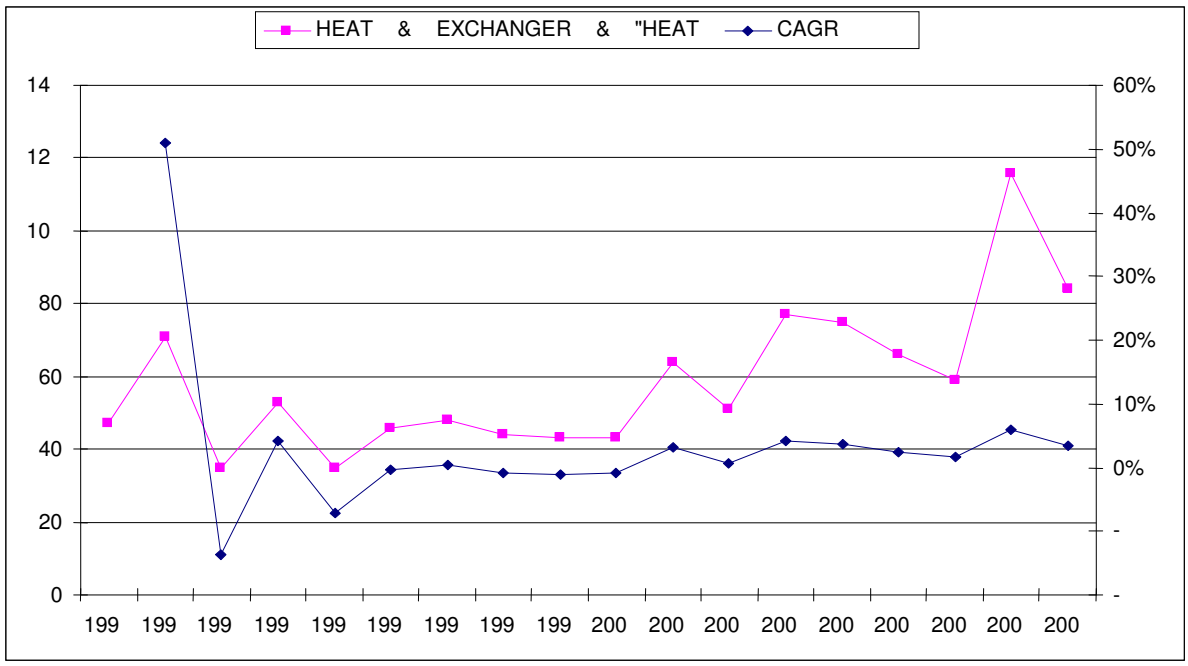
Figure 7

Source: Research study data



Graph 16

Source: Research study data

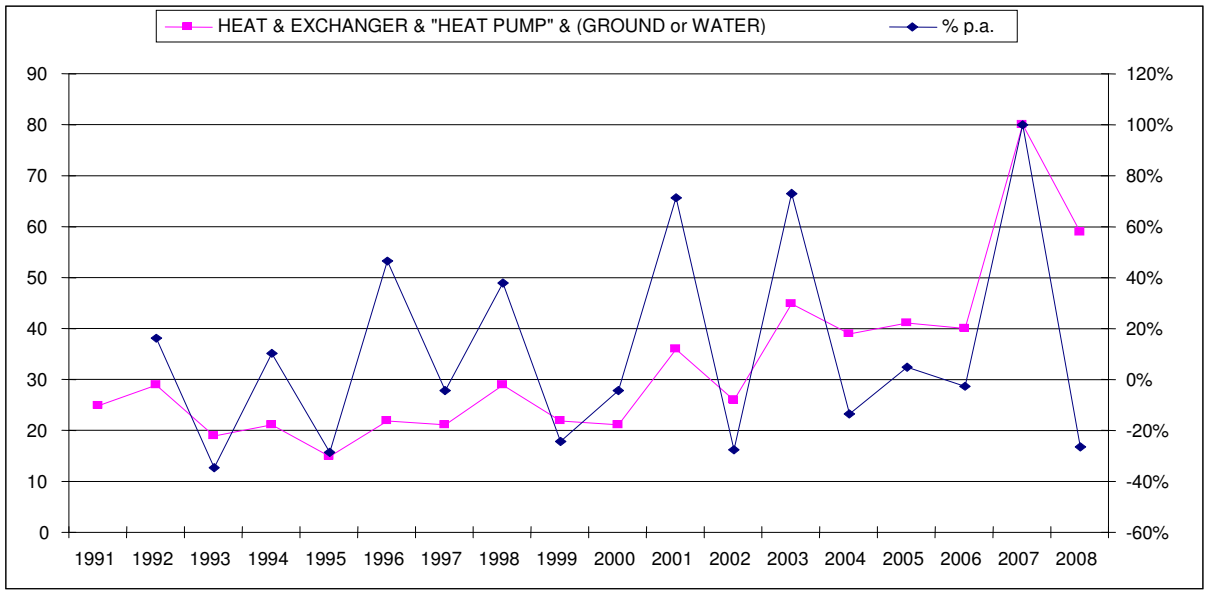


Graph 17

Source: Research study data

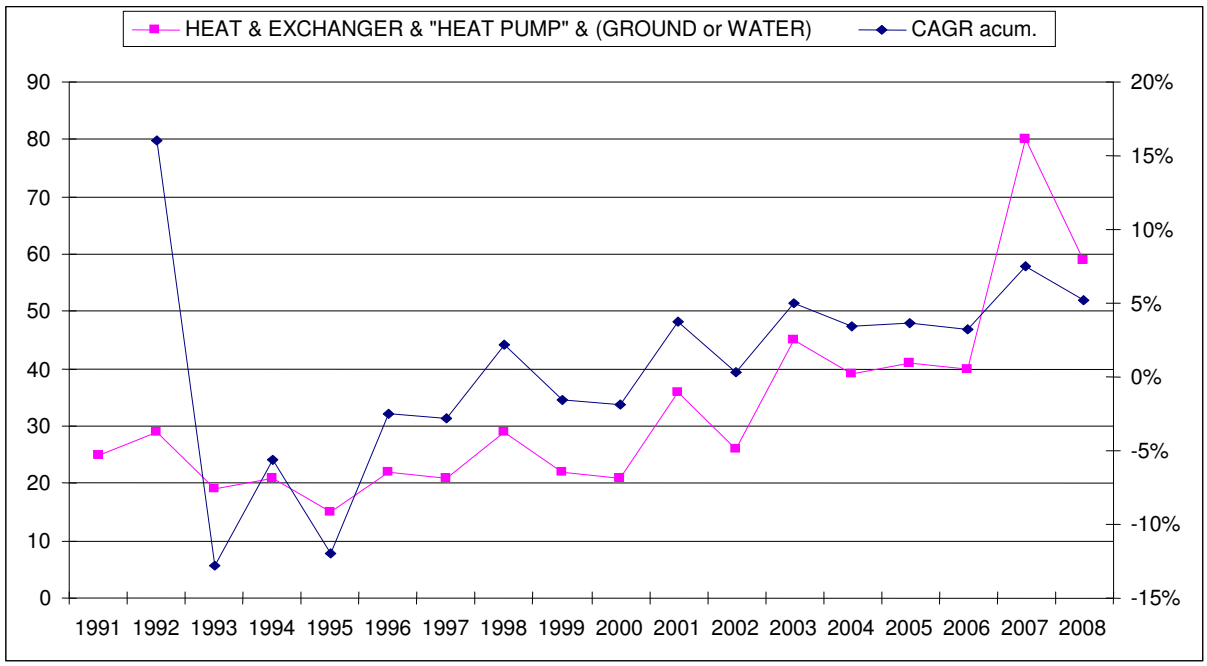
One can see that the development of research studies on "heat," "exchanger" and "heat pump," being broad and wide-ranging, has only marginal growth, which is small as compared to the total number of publications over the course of the years.

On the other hand, by adding the terms "ground" or "water" to the preceding terms, one finds that the growth shown becomes more significant, indicating that interest in the heat exchange phenomenon using a heat pump submerged in water or underground increased relative to the total number of research studies.



Graph 18

Source: Research study data



Graph 19

Source: Research study data

A group tracking the related technologies would be paying attention to this phenomenon in the mid-1990s. It is important to stress that the present study is attempting to evaluate whether bibliometric analysis, used to prospect and monitor emerging technologies, might indicate the development propensity of technologies connected with the use of geothermal heat pumps for the climatization of environments. One must keep in mind that this tracking would be conducted over the course of the analysis period and not afterwards. Other data analysis techniques are not used here, because the data up to 2008 would not be available to the researchers that would be implementing the tracking. Furthermore, the present study also conducts no confirmation of the total results and of the possible conclusions that might have been reached by the researchers during the prospection, as this was not the aim of this study.

Some of the terms previously chosen for tracking yielded no indication that they could have drawn the attention of the researchers. Terms such as "borehole," "u-tube," "vertical borehole," "coupled" and those connected with climate change showed no relevant association capable of indicating a connection between the technology tracked and possible technological pathways or new routes. However, this does not mean that henceforth they will not acquire relevance.

5 FINAL THOUGHTS AND RECOMMENDATIONS

Taking bibliometric analysis as a tool for tracking emerging technologies, this study showed that it can work as a means of identifying indications of greater interest and investment in certain technological pathways. It can also provide input into strategic decision-making connected with technology investments, particularly as a resource that reduces the degree of uncertainties in the decision-making process.

It was possible to verify that the tracked technology was a potential candidate drawing rising attention and it would have been possible to develop this perception by using bibliometry during the course of the period studied. Though this conclusion undoubtedly has its limitations, such as those explained above, the important aspect here is that the concept underlying the methodology is valid and applicable, provided one maintains the proper boundaries and definitions required to use the method.

Prospecting emerging technologies whose lifecycles may be consolidated a few years after the time when they were analyzed is a major strategic challenge, whether for organizations or governments. This study focused on evaluating the use of bibliometry to provide support for technology prospecting and thus to improve the degree of decision-making assurance. Decision-making as a field of knowledge has several academic contributions that must be taken into account when one is attempting to mitigate decision risks, especially when using prescriptive tools to provide support for decisions, and bibliometric analysis can contribute to the use of such tools. A good pathway for future research studies might be to research further the use of bibliometry combined with other prospecting methods, with a view to improving the potential inputs into decision-making.

It would be equally interesting to include tracking of the full content of publications, in order to calculate the semantic distance between terms. This approach might add further value to the capacity to identify emerging technologies, although it would increase the research process time.

As already mentioned, it might be interesting to consider integrating the use of bibliometric analysis with a methodology to consult experts, in order to find out whether bibliometric analysis would become more effective if conducted in stages that alternated with consulting experts, or if it might be applied after a preliminary consultation. This suggestion gained importance during the course of the present study, in which the process of consulting experts was replaced by bibliographic research on the related technologies.

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