Journal of Infrastructure, Policy and Development 2024, 8(2), 2190.
https://doi.org/10.24294/jipd.v8i2.2190

Review

Sustainable cities and Brazilian inventors: Environmental technologies on life cycle assessment in patent databases

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CITATION

Grunevald I, Kipper LM, Ribas Moraes JA. (2024). Sustainable cities and Brazilian inventors: Environmental technologies on life cycle assessment in patent databases. Journal of Infrastructure, Policy and Development. 8(2): 2190. https://doi.org/10.24294/jipd.v8i2.2190

ARTICLE INFO

Received: 1 June 2023
Accepted: 12 September 2023
Available online: 29 December 2023

Abstract: According to the United Nations, by 2050, about 68% of the world's population will live in urban areas. This population increase requires environmental resilience and planning ability to reduce the negative environmental impacts associated with growth. In this scenario, life cycle analysis, whose standards were introduced by ISO 14000 series, is an essential tool. From this perspective, smart cities whose concern about environmental sustainability is paramount corroborating SDG 11. This study aims to provide a holistic view of environmental technologies developed by Brazilian inventors, focused on life cycle analysis, which promotes innovation by helping cities build greener, more efficient, resilient, and sustainable environments. The methodology of this article was an exploratory study and investigated the scenario of patents in the life cycle. 209 patent processes with Brazilian inventors were found in the Espacenet database. Analyzing each of the results individually revealed processes related to air quality, solid waste, and environmental sanitation. The review of patent processes allowed mapping of the technological advances linked to life cycle analysis, finding that the system is still little explored and can present competitive advantages for cities.

Keywords: smart cities; life cycle analysis; environmental technologies; development; patents; sustainable development goals; SDG

1. Introduction

Organizational performance nowadays looks beyond the business's profitability, passing through several variables, including the environmental aspect, but not limited to this area. From this perspective, thinking about the organizational performance of cities is to understand that there are instruments that can help in the management processes. In this sense, sustainability must support economic growth, social development, and environmental protection, thus creating advantages, whether they are commercial or not (Mengistu and Panizzolo, 2022).

In the search for sustainable development, addressing environmental issues is crucial: Besides accelerating industrialization, it also mitigates harmful effects on sustainability. Since then, processes focused on an eco-efficient perspective have been initiated in environmental management systems, such as ISO 14001, in addition to the elaboration of environmental performance analyses and life cycle assessments, among others (Arvidsson et al., 2017; Haase et al., 2022).

Life cycle assessment can be a leading tool to guide sustainable development strategies (Fritsch Denes et al., 2022). The rapid urbanization of cities brought a possible solution, which consisted of the emergence of so-called smart cities, which seek to solve the sustainability problems arising from this scenario. Goal 11 of the Sustainable Development Goals (SDG) from the United Nations (UN) states, "Make cities and human settlements inclusive, safe, resilient and sustainable." Thus, this guide approaches cities from the point of view of the life cycle analysis, fostering sustainable development. Looking at this tool from the perspective of patents becomes relevant for promising and effective organizational performance management under the concept of innovation.

This study presents an innovative perspective by aiming to establish a constructive link between patents related to life cycle analysis and SDG 11 to develop a comprehensive approach that identifies processes contributing to a more sustainable and resilient future for urban areas. It is worth noting that after the publication of the SDGs, academic publications in the environmental field have identified 'life cycle analysis' as one of the most relevant clusters, with notable positive effects on urban waste management (Ye et al., 2023). Therefore, this study aims to provide a holistic view of environmental technologies developed by Brazilian inventors, focusing on life cycle analysis to promote innovation and assist cities in building greener, more efficient, resilient, and sustainable environments. The research question seeks to identify patent processes of Brazilian inventors related to life cycle analysis from the perspective of urban development.

Therefore, this article is divided into five sections: the first section briefly introduces the literature on organizational performance, cities, SDG 11, and their relationship; the second section presents a review of environmentally and economically smart cities, life cycle analysis, and patents; third section addresses the methodology used in this research; fourth section discusses the results and indicates state of the art; and finally, fifth section brings the conclusions and indications of possible future works.

2. Review of literature

Many cities are increasingly focusing their attention and efforts on achieving sustainable local systems from a public management perspective. The data is alarming, with estimates suggesting that 3.4 billion tons of urban solid waste could be produced by 2050. This issue requires an integrated approach from economic, environmental, social, technological, and energy perspectives (Ye et al., 2023). However, to promote urban development from all these angles, academic and technological studies need to advance, encompassing the state of the art and technique, which can be found in patent databases. This section presents smart cities, life cycle analysis, and patents.

2.1. Environmentally and economically smart cities

People and business development and space transformation occur within cities' scope. Structuring, planning, management, and many other topics are highly relevant to quality of life and sustainable development (Bento et al., 2018). Among the means to achieve SDG 11 (sustainable cities), particular attention is paid to target 11.6, which seeks, "By 2030, reduce the per capita negative environmental impact of cities, including paying special attention to air quality, waste management municipalities and others" (NU, 2023). Currently, 55% of the world's population occupies urban spaces. Considering the expected urban expansion, more significant investments and further research are required to mitigate water and air pollution, solid waste disposal, and unsustainable transport. Typically, cities are not originally designed to cope with population increase and concentration, and infrastructure redesign is limited (UN-Habitat, 2022; Salman and Haser, 2023).

Thus, it is observed that the planning and development of this locus occur from the ability to balance economic growth, social justice, and environmental protection, interests that can sometimes conflict with each other (van Stigt et al., 2013). Looking at these dimensions attentively and actively forms a way to achieve sustainability. According to Toli and Murtagh (2020), the urban environment can be sustainable when social equity, conservation of the natural environment and its resources, economic vitality, and life quality are achieved. In this way, innovation and new technologies, combined with productive systems and economic arrangements, reflect urban development focused on providing different possibilities and valuing intellectual and human capital (Glaeser, 2012).

The conceptualization of the present research emerges from the methodological concept of CHICS (human, intelligent, creative, and sustainable cities, translated from Portuguese). Transforming the city into a sustainable ecosystem requires involving people, developing new markets for the city's economy, addressing environmental issues, and using technology to improve services and facilitate connections. CHICS have six dimensions: smart governance—Participation and empowerment; smart people—Creativity and social capital; smart mobility—Infrastructure and transport; smart life—Culture and quality of life; smart environment—Resources and sustainability; and intelligent economy—Innovation and competitiveness. The last two are firmly applied to the life cycle analysis from an environmental and technological perspective (Porto, 2020).

Smart cities focus on data-based technologies, which are integrated and applied to environmental sustainability (Bibri et al., 2023). For the implementation to take place effectively, defining the strategies is fundamental: 1) formulating visible criteria when seeking technological solutions; 2) defining the necessary planning means to build synergies between the agents and actors involved; 3) organizing the necessary resources for implementation; 4) monitoring and evaluation of smart cities throughout their life cycle, metrics, and methods (Mora et al., 2023).

Bibri et al. (2023) added that environmental sustainability will be at the forefront of smart cities in the coming years, confirming the current trend of minimizing energy and water demand, waste and heat production, and air pollution. Thus, looking at possible technological solutions related to life cycle analysis is necessary.

2.2. Life cycle analysis and patents

To support decision-making, methods have been developed to assess environmental impacts in the life cycle of products, processes, or activities, where the life cycle assessment method has been applied as a management tool, pointing out loads of environmental issues and the potential impacts involved in the process (Zocche et al., 2015).

According to ISO 14001 (2015), the objective of an environmental management system is to control or influence how the organization's products and services are designed, manufactured, distributed, consumed, and discarded, using a life cycle perspective that can prevent the involuntary displacement of environmental impacts but still achieving financial and operational benefits that can result from the implementation of environmental alternatives that reinforce the organization's position on the market (ISO, 2015).

Studies have shown an increase in the production of clean technology inventions, thus expanding the rapid growth of patents, indicating that this area has contributed a lot to the subsequent technological advances. This can result from favorable institutional environments promoting clean technologies and innovation (Linnenluecke et al., 2019).

Using the information in patents is suitable for innovation studies, as such data can be classified into detailed technological fields and have been successfully applied in empirical research using data from the United States and the European Union. Patent information and data can be used to address determinants of the rate and direction of technological progress (Lin et al., 2018).

Patents are titles granted by the state, with temporary validity to the holders of patent processes, who, after being granted the patent application, begin to exercise territorial exclusivity over the technology object of the process. In Brazil, patents are divided between invention and utility model patents, valid for 20 years and 15 years, respectively, from the filing date. After the concession by the state, which occurs through a declarative act, once the legal requirements are present, the patent holder can exploit it commercially exclusively throughout the national territory (INPI, 2021).

3. Methodology

Conducting an environmental analysis based on patents is a great practice (Landi et al., 2023). Thus, based on the understanding that patents can signal the development of technologies and innovations, a prior art search was carried out in a patent database to identify the patent processes of Brazilian inventors related to life cycle analysis from the perspective of the development of cities. **Figure 1** depicts the flowchart outlining the structure of the conducted research, illustrating the phases and definition of the applied strategies.

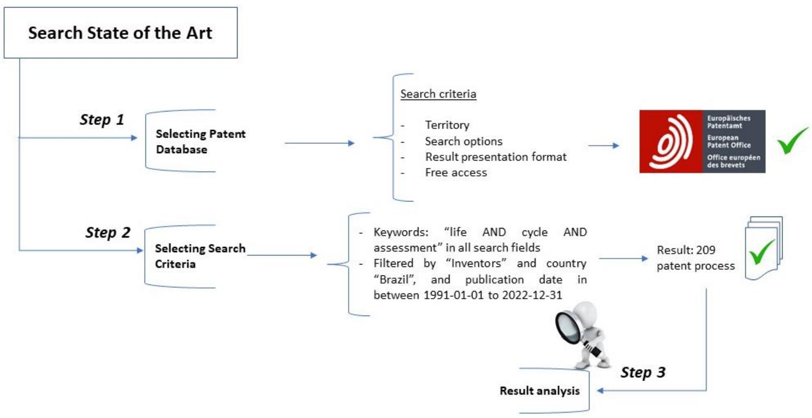

Figure 1. Flowchart for structuring patent research.

Step 1 aimed to select the patent database for exploration. The criteria adopted for this selection included territory, search options, result presentation formats, and free access. Through exploratory research, the European Patent Office (EPO) database was chosen. Espacenet, the EPO's base provides data on patent processes from more than 80 countries, including Brazil. The base used can be considered one of the most complete in the world, as it holds information on over 130 million patents. Access can be made free of charge through the link worldwide.espacenet.com. It is possible to combine various search fields. It offers numerous ways to explore the results, including the possibility of saving them in an Excel-compatible file and presenting some graphs for analysis.

Step 2 aims to establish criteria for searching for patents in the chosen database. The search used the terms "life AND cycle AND assessment" in all search fields and was filtered by "inventors," "Brazil," and publication date between 1 January 199 to 31 December 2022. The first publication date was defined from the first result listed. Initial data were obtained on 27 March 2022, and updated on 26 May 2023. This work treated results as processes, including patent applications, granted patents, and public domain patents.

It is important to note that some processes have not yet been published on the cut-off date for patent search. After the deposit, the processes remain confidential, and this period may vary depending on the country. In Brazil, after the patent application filing, the process remains 18 months in secrecy.

It is essential to highlight that defining the nationality of inventors (Brazilian inventors) does not limit the technologies to be applied or developed only in Brazil. Brazilian inventors contribute to technologies worldwide, and strategic considerations for the market application of that technology determine the territoriality of patent registration. Hence, it is possible to observe that many processes are not protected in Brazil.

Step 3 involves data processing, where the results are analyzed. For better understanding and avoiding misconceptions, the term "process" will be used for the patent search results since analyzing the patent status is not within the scope of this paper. The research showed 209 patent processes based on the listed criteria, and how they are presented was assessed. Air quality, environmental sanitation, and solid waste processes are highlighted. This is because, based on target 11.6 of SDG 11, Brazil has established that it will seek to achieve the following, "By 2030, reduce the negative environmental impact per capita of cities, improving air quality indices and solid waste management; and ensure that all cities with over 500,000 inhabitants have implemented air quality monitoring systems and solid waste management plans." (IPEA, 2023).

4. Results and discussion

The search to identify technologies related to life cycle analysis, developed by Brazilian inventors, resulted in 209 patent processes (**Figure 2**). The most recurring terms are 'method,' 'composition,' and 'use,' as they traditionally appear in patent process titles. For this reason, these terms were excluded from the word cloud composition, along with non-related words. This measure was taken to enhance the visibility of other words.

Figure 2. Word cloud from title.

The oldest application that met the search criteria was deposited in the Instituto Nacional da Propriedade Industrial (INPI) on 17 April 1990, authored and applied by Celso Savalli Gomes, titled, "Hydrogen sulfide removal filters and/or denitrification-dephosphation filters" (translated from Portuguese), under process number BR9001841. Among other applications, the process filter allows the anaerobic treatment of sewage.

The applicants with the highest number of processes are the Fundação Oswaldo Cruz (12), followed by the American company Human Genome Sciences (11), São Paulo Research Foundation (FAPESP) and Federal University of Minas Gerais (UFMG; 9 each), Butantan Foundation and the company Braskem (07 each), Avita International and University of São Paulo (USP; 06 each), and Embraer (5).

Most of the cases are published in the United States (110), followed by several other countries or offices: European Property Office (43), Canada (30), Brazil (12), and Korea (07), even considering the cases whose entry occurs via World Intellectual Property Office (121). It is necessary to note that the same technology may be present in more than one country if its applicant has requested protection in more than one territory.

The International Patent Classification (IPC) is an essential tool in patent processes because it organizes and facilitates access to technological information contained in documents. By identifying the most used classifications, the appointment of key performance indicators (KPIs) to evaluate the development of technologies in different sectors can be detected.

All patent processes, whether applied or granted patents, receive one or more classifications, which are grouped into eight sections according to the IPC (WIPO, 2021): section A—human needs; section B—processing operations; transportation; section C—chemicals and metallurgy; section D—textiles and paper; section E—fixed construction; section F—mechanical engineering; lighting; heating; weapons; explosion; section G—physics; and section H—electricity. The most used classifications in the 209 processes, considering the IPC, are those shown in **Table 1**. It is also possible to verify the "total uses" in the referred table, which indicates how many times each of the classifications was used in the 209 identified patent processes.

Table 1. IPC description.

Classification symbol	Description	Total uses
A61K31/00	Medicinal preparations containing organic active ingredients	56
A61K38/00	Medicinal preparations containing peptides	40
C07K14/00	Peptides having more than 20 amino acids; gastrins; somatostatins; melanotropins; derivatives thereof	36
C12N15/00	Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g., plasmids, or their isolation, preparation or purification	36
A61K39/00	Medicinal preparations containing antigens or antibodies	34
G01N33/00	Investigating or analyzing materials by specific methods	33

As can be seen, the most used classifications are those belonging to category A61, which describes technologies associated with "medical or veterinary science; Hygiene". It is important to note that each patent process can receive one or more classifications according to the scope of its content.

One can also observe the use of the main groups of the IPC, where, as illustrated in **Figure3**, there are no classifications related to sections F (mechanical engineering; lighting; heating; weapons; explosion) and H (electricity).

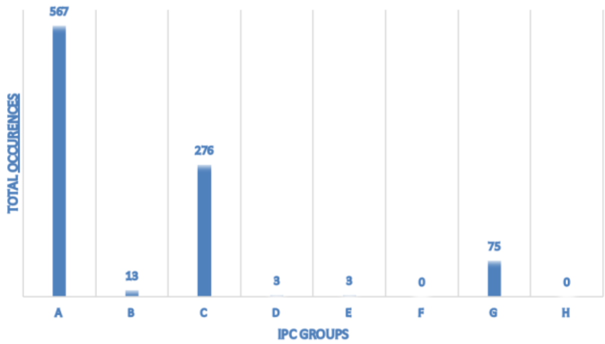

Figure 3. Total occurrence per group IPC.

The classifications of sections A (human needs), C (chemistry and metallurgy), and G (physics) were the most used: 61, 24, and 10 occurrences, respectively. Section B presented 4 occurrences, while D and E presented only one classification.

The Brazilian inventor with the highest number of processes is Reiner Gentz (11), followed by Irina Kerkis (6), Paulo Anchieta da Silva (4), Fernando Dotta (4), and Augusto Maria Durvanei (4).

Reiner Gentz's processes are related to the health area. C07K14 and A61K38 are among the most used classifications in all the analyzed processes. Another important classification is C07K16, corresponding to immunoglobulins, e.g., monoclonal or polyclonal antibodies.

Similarly, Irina Kerkis' processes also belong to the health area. In their patent processes, the classifications C12N5 (undifferentiated human, animal, or plant cells, e.g., cell lines; tissues; cultivation or maintenance thereof; culture media therefor) and A61K35 (medicinal preparations containing materials or reaction products thereof with undetermined constitution), with greater intensity.

The processes of the inventors Paulo Anchieta da Silva and Fernando Dotta are divided between inventions in the healthcare field and those related to transportation, as they appear as inventors in the same processes. These, in turn, highlight more intensely the classifications G01N29 (investigating or analyzing materials by the use of ultrasonic, sonic, or infrasonic waves; visualization of the interior of objects by transmitting ultrasonic or sonic waves through the object) and G01M5 (investigating the elasticity of structures, e.g., deflection of bridges or aircraft wings).

Finally, Maria Durvanei Augusto's patent processes are also related to health, where the most used classification is A61K31, which is among the most used classifications in the total number of searched processes. Subsequently, the classifications with greater intensity are C07C45 and C07C49, which indicate the preparation of compounds having C=O groups bound only to carbon or hydrogen atoms; preparation of chelates of such compounds, and ketones; ketenes; dimeric ketenes; ketonic chelates; respectively.

Classifications with greater intensity only among the inventors highlighted with the largest number of processes are highlighted in **Figure 4**.

Figure 4. Rankings among inventors with the highest number of processes.

The group with the highest classification intensity in the patent processes is group C, which includes technologies from the chemistry and metallurgy sectors, followed by group A, where the technologies identified by human needs are classified.

Based on this, the assessment of results from an environmental perspective becomes relevant since processes for environmental sustainability in cities can be implemented through the innovations and technological optimizations claimed therein (Landi et al., 2023). An analysis of the 209 patent processes highlighted some related explicitly to SDG 11, presented in **Table 2**. The air quality area of application was defined as all inventions that refer to air pollution and others specifically related to air quality as a benefit. Inventions identified as ecologically correct seeking to reduce polluting agents and environmental effects were categorized as application areas in solid waste. Inventions related to recycling or processes that help environmental aspects regarding infrastructure were classified as environmental sanitation. It is important to note that the main application area was highlighted, but the same process may be related to more than one application area.

Table 2. Patents process related to ODS 11.

Process number	Title	Application area
US2022185922A1	Bio-based eva compositions and articles and methods thereof	Solid waste
WO2020049366A1 US2022169840A1	Biocompatible low impact CO_2 emission polymer compositions, pharmaceutical articles and methods of preparing same	Solid waste
EP3575654A1	Equipment for repairing ducts	Environmental sanitation
BR9001841A	Hydrogen sulfide removal filters and/or denitrification-dephosphation filters (translated from Portuguese)	Environmental sanitation

Table 2. (*Continued*).

Process number	Title	Application area
US2022306508A1	Granulated water treatment plant sludge composition containing mineral additives and respective preparation process	Environmental sanitation
EP3398988A1 US10934398B2	Method for obtaining a colloidal dispersion, colloidal dispersion and use thereof	Solid waste
CA2798880A1	Method for producing organic and organo-mineral fertilisers with high carbon concentration using physical and biological process	Solid waste
WO2017106941A1	Method for treating waste water using a culture of polysaccharide-excreting micro-algae, and use of micro-algae	Environmental sanitation
US2013140990A1	Open LED detection and recovery system for LED lighting system	Environmental sanitation
WO2021165751A1	Polypropylene-based compositions incorporating post-consumer resin and methods thereof	Solid waste
US2018014569A1	Portable deposit compartment for waste collection	Solid waste
EA038153B1	Preparing fatty acid soap bar comprising potassium soap from oil stock of low Iv	Solid waste
US2012167648A1	Processes and apparatus for small-scale in situ biodiesel production	Solid waste
EP2479345A1	Rainwater channel drain	Environmental sanitation
WO2021056087A1	Recycled hexane and uses thereof	Solid waste
US2022145756A1	Seafloor harvesting with autonomous drone swarms	Solid waste
US2022058317A1	Smart process control system for continuous treatment of felts	Solid waste
US2013269240A1	Ternary fuel compositions containing biodiesel, plant oil and lower alcohols for feeding diesel-cycle motors	Air quality
WO2015081402A1	Unit for producing pozzolanic cement of low environmental impact, obtained from mixed construction and demolition waste (CDW), process and resulting products for civil engineering	Solid waste
WO2021113944A1	Use of autogenous mill in separation method for recyclable materials in led lamps	Environmental sanitation

It is observed that a minority of the selected processes is related to air quality, and the majority is related to solid waste according to the criteria established for the classification. Many of the patent processes resulting from the research are directly related to the health area (identification, treatment, and prevention), the reason they are not included in this table.

5. Conclusion

Looking at patent processes is fundamental for organizational performance management because such information allows for mapping technologies, evaluating investments, and indicating technological trends.

It is observed that the life cycle analysis among the patent processes of Brazilian inventors is related to the chemical areas, including pharmaceuticals and human needs, with a greater tendency to develop specific technologies. Knowing that there is an academic tendency to relate life cycle studies to environmental issues, this hypothesis is not confirmed when evaluating the patent processes of Brazilian inventors.

209 processes with Brazilian inventors were found in the search carried out on the Espacenet database. Reiner Gentz, Irina Kerkis, Paulo Anchieta da Silva, Fernando Dotta, and Augusto Maria Durvanei were the five inventors who contributed to most of the processes, which originated in different countries. The most used International Patent Classification in all 209 cases is “Medicinal preparations containing organic

active ingredients” (A61K31/00), while if only the processes of the five greatest inventors were considered, it would be “Peptides having more than 20 amino acids; gastrins; somatostatins; melanotropins; derivatives thereof” (C07K14). It was also observed that the oldest process dates from 1990, and the applicant with the largest number of processes is the company Human Genome Sciences.

From what was observed, few inventions still seek environmental solutions that can be applied to cities specifically. This seems understandable since most inventors are linked to companies or initiatives that seek private solutions in the foreground. The intellectual property system, patents in particular, provides for the economic exploitation of the invention as a counterpart for its development and disclosure but in no way prevents the invention from being transferred to the public sector, which, as a rule, is primarily responsible for meeting the environmental demands of cities. Of the 209 selected patents, only 22 pertain to SDG 11, from which only one focuses on air quality, a problem that worsens significantly in urban centers. Achieving sustainable urban development necessitates collaborative and interdisciplinary efforts and a solid understanding of urban challenges and available technologies to bring about the necessary and sustainable change. A significant bottleneck is perceived for developing technologies focusing on air quality, environmental sanitation, and solid waste with the potential to be used by city structures worldwide.

Future studies can assess the status of the processes, that is, an in-depth assessment of whether they have been granted, are in force, or are already in the public domain. Furthermore, expanding the study to other countries besides Brazil shows an interesting perspective, as it will describe the global situation of sustainable development. Furthermore, a thorough exploration of existing technological solutions enables the identification of knowledge gaps and improvement opportunities. These can be highlighted as solutions for more sustainable cities.

Acknowledgments: Thanks to the Graduate Program in Environmental Technology (PPGTA)—UNISC, Coordination of Superior Level Staff Improvement (CAPES) and National Council for Scientific and Technological Development (CNPq)—productivity scholarship—(grant number: 310204/2022-4).

Conflict of interest: The authors declare no conflict of interest.

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