

Research

Navigating sustainability: challenges and opportunities in eco-friendly paint manufacturing practices in Portuguese industries

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Abstract

Environmental degradation and public health are undeniably linked to industrial pollution, which is progressively getting worse every day. This reality requires a proactive change in companies to actively reduce the significant environmental impact of chemicals consumption, especially in paints and varnishes, which tend to be more toxic than other products. Despite this urgent need, there is a significant gap in the environmental commitment of Portuguese civil engineering paint manufacturers. To address this issue, a targeted questionnaire was distributed to 90 companies in different regions of Portugal, on 41 companies provided valuable insights into their practices. Data collection involved a structured questionnaire distributed to production managers, focusing on six conceptual frameworks relevant to paint industry practices. The data was methodically organised allowing statistical analysis such as T-tests and Chi-square tests. The results showed that 59% of the companies had a low level of environmental commitment, lacking the necessary departments for eco-friendly practices (or sustainable practices) and effective marketing campaigns to promote sustainable products, particularly waterborne paints, which are crucial for reducing consumer exposure to harmful solvents.

Keywords Sustainability · Eco-friendly Practices · Paint manufacturing · Environmental commitment · Portuguese industries · Consumer preferences

1 Introduction

In recent years, the global population has experienced substantial growth, prompting concerns regarding the potential insufficiency of housing in certain regions in the foreseeable future. It is projected that by the year 2050, the global population will reach approximately 10 billion individuals; thus, it is reasonable to contemplate that the expansion of the construction sector over time, along with its concomitant waste generation (including paints and materials), would exhibit a parallel trajectory. This anticipated growth necessitates a critical examination of sustainable practices within the construction industry to mitigate environmental impacts and promote resource efficiency, mostly in painting manufacturers due to the nature of the compounds used in their products [1, 2].

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The advancement and evolution of the paint industry can be traced back to 1970, which marks the establishment of the inaugural factory in England, subsequently leading to uninterrupted development. Considering the substantial growth witnessed within the real estate sector, there has been an enterprising increase in paint demand, resulting in a tendency towards augmented production levels. Nevertheless, throughout its historical progression, the domain of paints has undergone multiple phases of development, during which certain raw materials that were once permissible have since been prohibited due to their toxicological properties [3].

Given that paint is classified as a chemical product, specific regulations are delineated in Portuguese legislation that must be adhered to. Throughout its history, the paint and varnish sector has confronted numerous challenges, particularly regarding the implications and ramifications of its operational activities on the environment. In response to pressures exerted by governmental bodies and capitalist frameworks, representatives from the industry have begun to adopt alternative formulations aimed at mitigating environmental impacts while simultaneously enhancing profit margins [4].

The functionality of these products is a criterion that must be followed, without neglecting social and environmental requirements, such as the elimination or reduction of emissions of volatile compounds and toxic compounds from some materials that are toxic in paints and other types of materials used internally in civil construction [5, 6]. What are the specific requirements for paint manufacturers and other building materials to produce a sustainable material? The industry must define specific technical requirements for the materials to be purchased and used in construction. The change in consumer thinking about products is directly reflected in the manufacturing choices of the industry, i.e. a consumer with a more sustainable mindset will generate some necessary changes in the product process and in the selection of the raw materials that make it up [7].

Strategies to formulate a more sustainable material are subject to a series of evaluative procedures: manufacturers are obliged to provide the requisite tools for this purpose, in a precise and meticulously structured manner, to ensure that all consumers and designers have comprehensive access to the criteria, thereby facilitating the decisions that must be undertaken. For consumers to achieve optimal selections concerning more sustainable materials. Educational initiatives must accompany these tools, empowering consumers with the knowledge needed to understand the impact of their choices on the environment and encouraging responsible consumption practices [8].

These innovative approaches not only comply with regulatory standards but also respond to growing consumer demand for sustainable products, reflecting a significant shift in market dynamics. As a result, companies are increasingly investing in research and development to create eco-friendly solutions (or sustainable solutions) that align with both environmental goals and consumer preferences. This trend is further bolstered by collaborations with environmental organizations and the integration of circular economy principles, emphasising resource efficiency and waste reduction [9].

Portugal is one of the most important producers of paints and varnishes in Europe, with companies of various sizes involved in the production of these materials in the country, some of which have achieved international recognition [10].

The paint manufacturing sector is closely linked to environmental degradation due to the toxic chemicals often used in the products. The Portuguese paint industry's commitment to sustainability appears to be evolving, albeit at different speeds and depths across the different dimensions of sustainability. Portuguese companies, including those in the paint industry, recognise sustainability as a strategic issue and often integrate it into medium and long-term plans. However, the focus of reporting tends to be qualitative rather than quantitative, resulting in a lack of comparability and transparency [11].

The implementation of social sustainability practices in the Portuguese industry is generally low, with basic practices. More advanced practices need to be better promoted and encouraged, with collaboration with suppliers and the involvement of NGOs and community groups [12]. Environmental practices are progressing, particularly in companies in the northern region of Portugal, which have shown improvements in implementing sustainability measures. However, there is a need to implement more effective mechanisms to ensure compliance and control of these practices [13].

Although there is a clear strategic commitment to sustainability in the Portuguese industry, including the paint sector, the depth of this commitment varies, although the intention is there, and a deeper intervention is needed so that the implementation of sustainable practices can develop and be quickly standardised.

To understand why the adoption of environmentally friendly practices in Portuguese paint companies is still a challenge, this study aims to assess whether the environmental policies adopted are adequate to raise awareness of environmentally friendly practices in the production process and whether they comply with standards such as those established by the Portuguese Association of Paint Manufacturers (APT) [14] and/or the ISO 14001 standard [15]. There is a growing trend towards reporting on the 17 Sustainable Development Goals (SDGs), albeit at a slow pace, with companies typically disclosing information on around half of the 17 SDGs, depending on the type of industry and compliance [16].

Many Portuguese paint manufacturers are beginning to recognise sustainability as a strategic issue. These strategic actions include 6 of the 17 SDG goals: (i) SDG 4—Quality Education: empower consumers with knowledge about the environmental impacts of their choices, which can drive demand for more sustainable products, (ii) SDG 9—Industry, innovation and infrastructure: Encourage industry to adopt sustainable practices and promote innovation, (iii) SDG 4—Quality Education: empower consumers with knowledge about the environmental impact of their choices, supporting industry to develop more sustainable products, (iv) SDG 12—Responsible Consumption and Production: emphasises the need for sustainable practices in industry to minimise waste and pollution, (v) SDG 13—Climate Action: Adherence to specific regulations set out in Portuguese legislation, which can reduce emissions and promote environmentally friendly practices, and finally, (vi) SDG 17—Partnerships for the Goals: through the integration of circular economy principles and collaboration with environmental organisations, the sustainability of the paint sector can be increased.

In Portugal, the industries that produce the most environmental indicators and stakeholder engagement are those in sectors such as the paper industry, driven by public pressure and the need to meet stakeholder expectations. Every year, they produce reports on energy, emissions, effluents and waste, which can serve as a model for the paint industry [17].

Therefore, to assess whether Portuguese industries have implemented sustainable management policies in their production process, this study has assessed, through statistical analyses, whether the policies adopted have influenced the main sectors of the industry, such as the reduction of the use of high or moderate toxic substances, the recruitment of people responsible for the acquisition of raw materials and the production process with academic qualifications appropriate to the sector, and whether these factors have a direct impact on the production of materials with reduced toxicity levels, the existence of a dedicated research and development (R&D) department, and whether the marketing strategies of Portuguese companies influence consumer preferences for more environmentally sustainable products.

Finally, the manuscript emphasises the urgent need for improved environmental practices in the paint industry, along with consumer education and legislative support, to promote a transition to more eco-friendly manufacturing processes. The study serves as a call to action for stakeholders to prioritise eco-friendly practices and improve the overall sustainability of the paint manufacturing sector.

2 Materials and methods

2.1 Data collection and experimental research

To collect data, an exploratory survey was conducted using online search engines and information provided by the APT [14] institution. For this study, the questionnaire was developed based on relevant industry literature and reviewed by experts in the field, including academics and professionals from the paint industry. Before its final use, a pre-test was conducted with the paint company to identify possible ambiguities and inconsistencies in the questions. This process allowed adjustments to be made to improve clarity and ensure that the questions captured the desired information objectively. In addition, strategies to reduce bias were employed, such as neutral wording of questions to avoid inducing responses and the inclusion of control questions to check the consistency of participants' responses. Although the questionnaire was not formally peer-reviewed before use, its construction followed good methodological practice to ensure the reliability and validity of the data collected.

The questionnaire was sent to all companies registered with the APT, which was approximately 90 companies, ensuring that all companies had the opportunity to participate. The current number of paint manufacturing companies operating in Portugal, the size of the company and its geographical location were listed. The selected companies were invited by email and telephone to participate in the survey. After acceptance, a specialized questionnaire comprising 37 questions meticulously developed was sent to the companies. This questionnaire included open and closed questions focusing specifically on topics such as environmental issues, safety protocols, corporate environmental management and sustainable ideals, among other topics relevant to the research problem. Information was also requested on the number of employees in each company, the monthly average of products produced in litres, revenue, exports and locations. All of this contributed to understanding the size of the selected companies and their respective sectors. However, only 41 companies responded, resulting in a response rate of 45.5%. Despite the response rate, the sample still covers a significant portion of the sector and includes companies of different sizes and production profiles.

Several inquiries were also designed to validate other responses through data cross-referencing, thereby enabling an assessment of the consistency of the provided answers. Google Docs® was selected as the platform for the questionnaire's

design, as it is recognised for its user-friendly interface and provision of essential tools for the efficient transmission and reception of data. Upon completion of the questionnaire, it was disseminated via electronic mail to the respective production managers of each organization included in the sample. The inquiries were deliberately chosen to align closely with the overarching objective of this study; consequently, 6 distinct categories were delineated, representing 6 conceptual frameworks that informed the formulation of the questions essential for effective data analysis. In Table 1, the identified conceptual frameworks and the inquiries generated through the brainstorming process are presented for review. The classifications outlined in Table 1 were established to streamline the questionnaire development process and facilitate the construction of both direct and indirect objective inquiries.

Group 1 seeks to acquire comprehensive data concerning the operational activities and sectors present within each Company, including the marketing department, research department, and the management of effluents, gas emissions, and waste, as well as the existence of an analytical laboratory, among other pertinent aspects. Group 2, the enquiries focus specifically on the individual responsible for procuring raw materials and supervising production within the Company emphasising the individual's age and educational qualifications. Group 3 is oriented towards examining the certifications held by the Company. Group 4, the objective is to evaluate the magnitude of the Company, which is assessed through metrics such as employee count, production volume in litres, and geographical location, among other factors. Group 5 aims to gather information regarding the manufacturing processes of various products, including varnish, and distinguish between toxic and non-toxic items. Lastly, Group 6 encompasses inquiries related to sustainability aiming to evaluate the Company's existing perspectives on environmental considerations and eco-friendly practices.

2.2 Survey data processing

Once the data were received, they were tabulated and some graphs were created using Excel® software. The statistical treatment of the data, such as mean and standard deviation for each research group. The statistical data analysis was carried out using the Statistical Package for the Social Sciences, SPSS (IBM®), version 22.0 [18]. To test the normality of the data, the Shapiro–Wilk test was selected in the software used for statistical analysis (SPSS), being a simple test suitable for this sample size and one of the most common normality tests. After checking the normality of the parametric data, i.e. data with a normal distribution, the T-student test [19] for 2 independent samples was chosen because of its simplicity and efficiency for this sample size.

For the qualitative samples, the Chi-square test [20] for independent samples was chosen in the SPSS software. This test is the most appropriate as there are more than 2 groups related to each other. The significance level chosen was 5%. To ensure the statistical validity of the T-test and Chi-square test, the data distribution and its conformity to the assumptions of these tests were examined. In the case of the T-test, which compares means between groups, although in most analyses with this test, one group had more than 30 observations and the other had fewer, the normality of the data was verified using the Shapiro–Wilk test, ensuring the appropriateness of the analysis. Furthermore, statistical studies demonstrate that the T-test can be reliably applied when at least one of the groups has $n \geq 30$, due to the robustness of the mean estimator under the Central Limit Theorem. The Chi-square test, used to analyze associations between categorical variables, was applied with attention to the expected cell size, ensuring the validity of the results [21].

Table 1 Questionnaire group according to Company sector classification and their activities

Groups	Activities considered variables
Group 1: Activities/Sectors existing in the Company	Advice from the marketing department Existence of the R&D department
Group 2: Necessary information from those responsible for the Company	Responsible employee with higher education in courses related to the environment
Group 3: Certifications	Company certification
Group 4: Company-specific information	Company size
Group 5: Level of toxicity presented in production and products	Water-based and solvent-based varnishes as a percentage of sales Percentage of production related to toxic and non-toxic products
Group 6: Sustainability	A predominant factor in the choice of raw material Environmental policy advice Sustainable thinking

3 Results and discussion

3.1 Company information: activities and sectors

Figure 1 shows in detail the number of companies analysed in this study, a total of 41 companies spread across several regions of Portugal, out of a total of 90 companies invited to this study, resulting in a response rate of 45.5%. From the information contained in this figure, it is possible to highlight the size of each Company, with 20 being small, 13 medium and 8 large companies.

After contacting each Company, it was possible to establish that there are many Companies producing paints and varnishes in Portugal, distributed in the North, Centre and South regions, differentiating between small, medium and large Companies. The locations of these Companies were obtained by telephone to confirm the location of the headquarters of each Company studied. Figure 2 shows a Portugal map with the location of the Companies.

As can be seen on the map provided in Fig. 2, the red dots represent the Companies analysed and their respective regions, and these companies were willing to participate in this research. In the northern region, there is a large company concentration where the majority are in the Porto district; 22 companies 12 are small, 6 are medium-sized and 4 are large. In the central region, there are 9 companies, 6 are small and 3 are medium-sized, and finally, in the southern region there are ten Companies, 2 are small, 4 are medium-sized and 4 are large (Fig. 1).

Another relevant information for this study is whether the companies export, since exports enable the international propagation of the brand itself, usually bringing increased demands from this market. As can be seen in Fig. 3, only 23 out of 41 can export their products, and of these 23 companies, 4 are small, 11 are medium-sized and all large companies export the paints manufactured in their units.

In the paint industry, numerous sectors play a central role in product development, encompassing the initial reception of raw materials to the rigorous quality control processes post-manufacturing. However, 2 areas are equally important if used effectively: marketing and research. The latter is of great importance in the coatings industry, particularly in terms of environmental considerations and new product development, where innovative technologies can be identified that allow significant improvements and developments to be made to the product itself. In essence, although the organization must allocate financial resources to this department, the return on investment is typically assured. The marketing department is no exception to this principle. Regrettably, not all organizations possess a designated department solely for marketing, which is critically important, as it is the responsibility of this department to effectively promote the developed product. A significant number of organisations use unprofessional marketing strategies to promote their products, undermining the importance of the marketing department.

Only 5 companies do not have a marketing department, whereas 36 possess a marketing department within their organizational structure (Fig. 3). Nevertheless, the prevalence of a research department remains relatively constrained among companies, with only 14 companies indicating the presence of such a department. Another significant domain

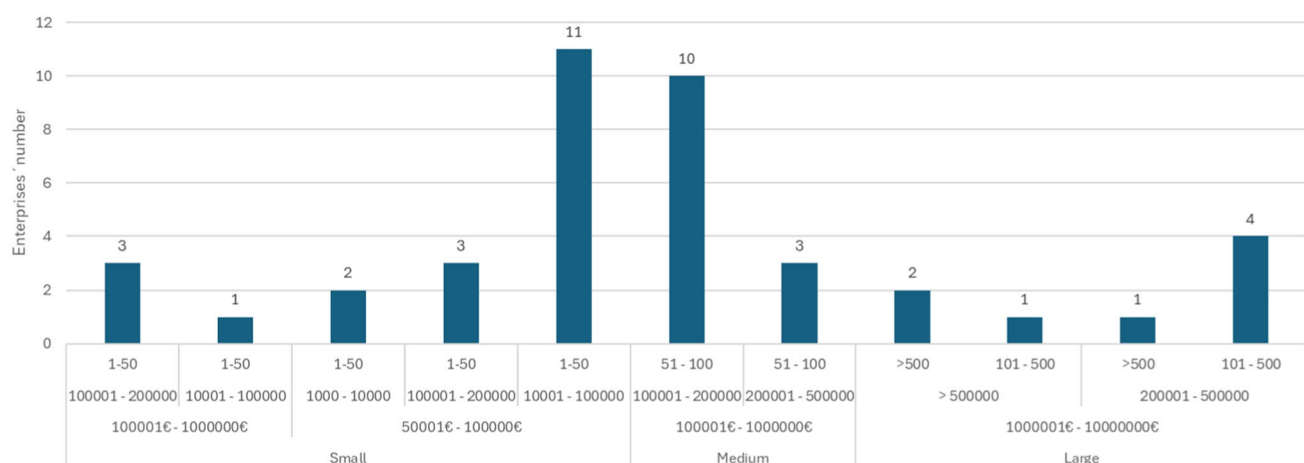
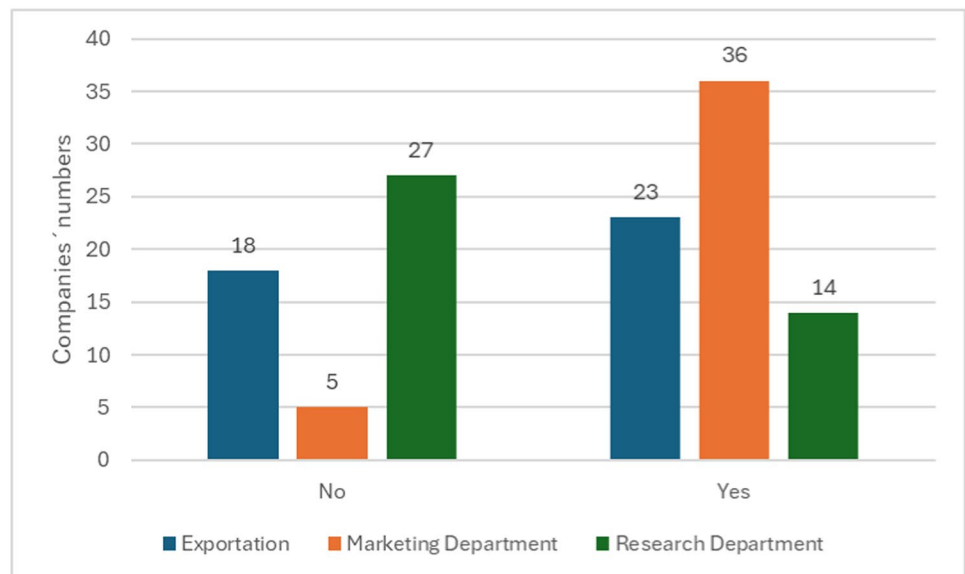


Fig. 1 The graphic represents the Companies' size related to the employee number, Annual Turnover (€) and Average monthly production of paints for construction (litres)

Fig. 2 Portugal map and the company location marked with the red dot [16]



Fig. 3 Exporting Companies number related to the marketing and research department



within an industry, in a broad sense, is the procurement sector, where the optimal suppliers, environmental considerations, and economic criteria are typically evaluated. The paint industry exemplifies this trend. Nonetheless, it became imperative to ascertain the market consultation methodologies that companies typically employ either periodic or

systematic. Periodic analysis is consistently conducted at fixed intervals, while systematic analysis, regarded as a more efficacious approach, is informed by a specific framework that addresses the necessity for procurement, irrespective of temporal considerations or immediate demands.

Most Companies have a methodical approach to raw materials purchase; specifically, of the 41 organisations surveyed, 24 consult the raw materials market systematically, while 17 organisations consult it intermittently (Fig. 4a). It is noteworthy that of the 17 organisations that habitually consult the raw materials market, 13 are classified as small Companies, 2 as medium Companies and 2 as large Companies. After the raw materials purchase, 2 other functions that are also important and relevant for the purchasing department are the systematic verification of the raw materials received and the availability of a laboratory for the raw materials analysis (Fig. 4b). The primary objective of the first function is to ensure that all aspects of the receipt of raw materials are in order, particularly in terms of packaging integrity, quantity accuracy and adherence to delivery schedules. The second is in the laboratory environment, where the quality of the raw materials themselves is verified.

From Fig. 4b only 3 out of 41 Companies do not have a systematic raw materials receipt analysis, all of them are small Companies. However, there is a balance regarding the existence of its laboratory for the raw materials analysis: 20 out of 41 Companies have their laboratory, while all large Companies have their laboratory in their units, in other words, 6 medium Companies and 14 small Companies do not have this support in their production units.

To understand the amount of toxic raw materials in solvent and water-based varnishes, questions were asked about the Company sales percentage of each varnish type. Figure 5 shows that all Companies sell more than 50% of solvent-based paints, meaning consumers still prefer this paint type. However, some companies have developed in terms of selling water-based varnish, with at least 5 Companies accounting for at least 40% of their sales in water-based solvent-based varnish. As seen in the literature review for this study [22], solvent-based varnishes are extremely toxic and contain VOCs that are extremely hazardous to human health.

In addition to the percentage of varnish sales shown in Fig. 5 2 questions were asked about the quality and value of the varnishes. The first question was which varnishes offered the best quality in terms of application and durability. The answer was unanimous, with all Companies reporting that solvent-borne varnishes have generally the best quality. The second question asked which varnish had the highest price and again the answer was unanimous, with water-based varnish having the highest price. Another question that received a unanimous answer was the treatment of wastewater, gaseous emissions and industrial waste, as according to the questionnaire, all Companies carry out such treatments.

3.2 Employees profile

As some departments in the Companies analysed are important for this work, the heads of these departments were also important for the study. Therefore, special emphasis is placed on the heads of 2 departments in the Companies studied, namely the head of production and the head of purchasing. Information on education and position allows a better understanding of the specific knowledge of each employee. Figure 6a shows the position of the interviewee within the Company and the preference for the use of the questionnaire was directed towards the production manager of each

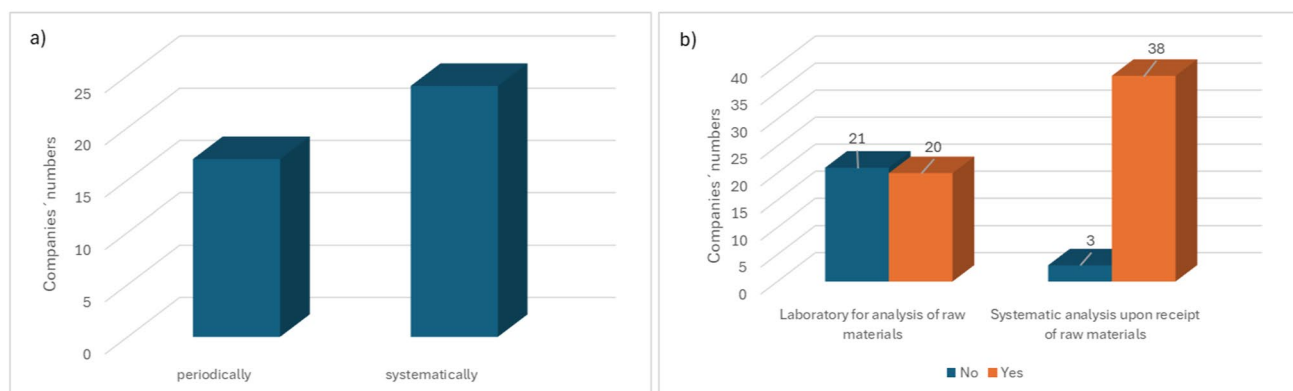


Fig. 4 **a** Companies' numbers opting for periodic or systematic advice on raw material purchase and **b** Companies' numbers with systematic raw material reception analysis and laboratory

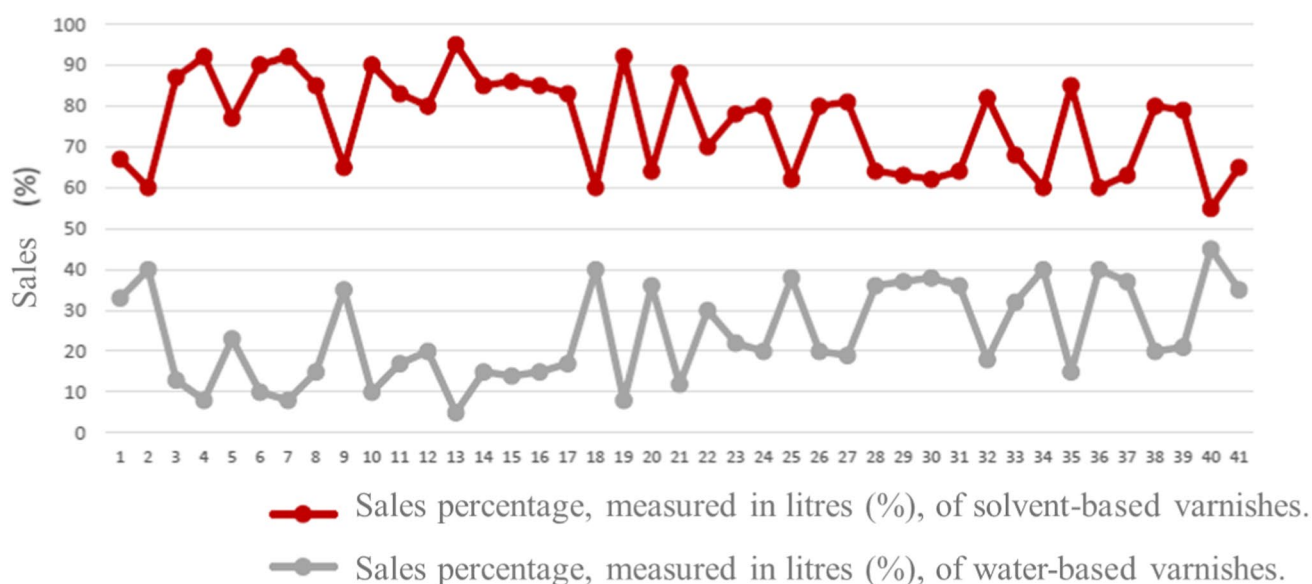


Fig. 5 Each company's sales percentage, measured in litres, of water- and solvent-based varnishes

Company. However, anyone with knowledge of production and a relevant position in the Company could also contribute to the research with their answers.

As priority was given to those responsible for production in the Companies, Fig. 6a shows that of the 41 questionnaires sent to the Companies, only 29 questionnaires were completed by them. However, as mentioned above, other relevant positions in the Company would certainly be able to answer the questionnaire if the employee responsible for production was not available. Thus, 2 questionnaires were answered by the CEO, 4 by the General Manager and 6 by the Industrial Director. Of the positions mentioned, all normally have greater responsibility in the organisation than the production director, so the responses were considered valid. Another very important employee for this study is the employee responsible for purchasing raw materials. Figure 6b shows the percentage of education of those responsible for this area in the Companies that responded to the survey. It shows that 32% of those responsible for purchasing raw materials do not have any higher education, and 18% have training, but not in areas that can provide adequate knowledge of environmental awareness. Therefore, only 50% of Companies have those responsible for purchasing raw materials with higher education and courses with skills that can transmit environmental awareness.

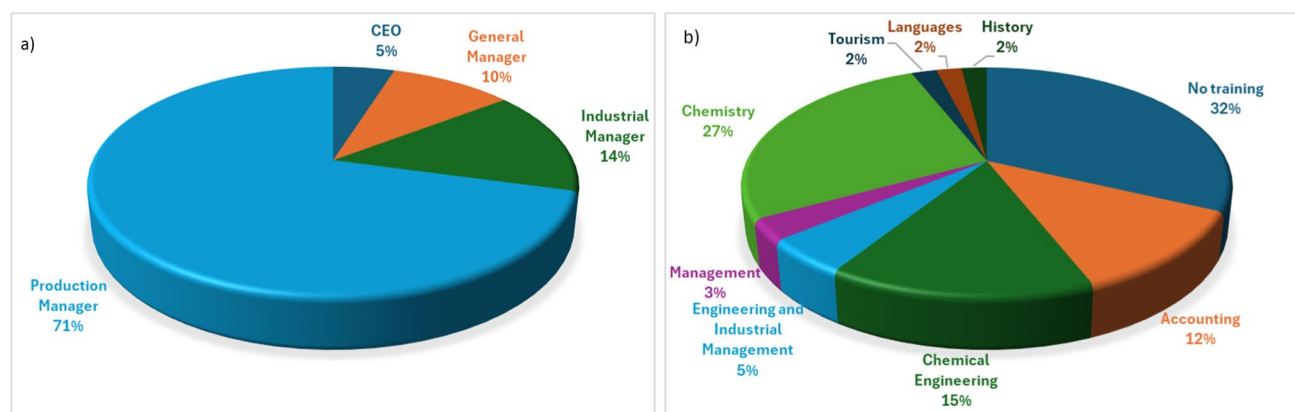


Fig. 6 **a** Employees' position who answered the questionnaire and **b** Correlation of the employee's percentage responsible for the Purchasing sector with higher education courses

In the second phase of this study, the results regarding the sectors/activities in each Company, also contain data on the education level of the person responsible for purchasing raw materials, the percentage of manufactured products that are toxic, and finally, the percentage of water-based varnish sales.

From 20 small companies interviewed, only 8 of those responsible for purchasing raw materials have higher education degrees, but of these 8 companies, only 4 have managers with higher education degrees who have specific knowledge of the environment. About the marketing department, only 5 companies have an active marketing department, to influence higher sales of water-based varnish, 4 do not have this department in their units, and the remainder have the department, but do not carry out technical campaigns focused on the issue of water-based varnish. For the R&D department, only 4 companies claim to have this department in their units. With the percentage of sales of water-based varnish, the company that demonstrated the best percentage with 40% of sales, while the worst result was only 5%.

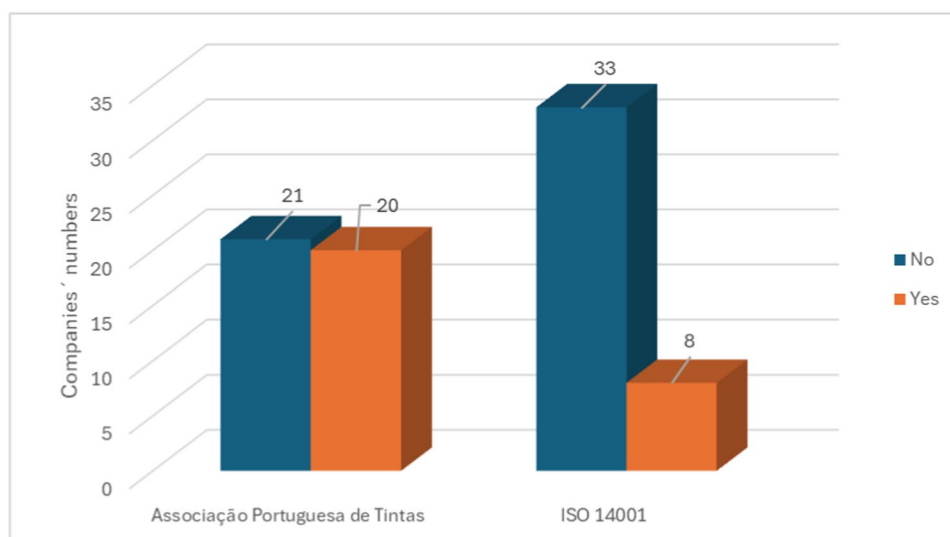
For the results of medium-sized Companies, it is possible to verify that 12 out of 13 companies have people responsible for purchasing raw materials with higher education, and of these, 11 have specific knowledge focused on the environment. Regarding the marketing department active in campaigns for the use of water-based varnishes, only 6 Companies adopted this type of procedure, and only one does not have a specific marketing department in its unit when questioned, the person in charge said that when they needed publicity, the Company hires an external Company. Thus, in this segment of medium-sized companies, only 6 have a marketing department, but they do not systematically carry out awareness campaigns for the use of water-based varnish. Regarding the R&D department, only 5 Companies have this department in their units. Regarding the percentage of water-based varnish sales in the total business volume, there is a very significant balance in sales, but even so, there are discrepant points. For example, one Company has 12% of water-based varnish sales, while two other Companies have 38% each.

Regarding the results of large Companies, all those responsible for purchasing raw materials from these Companies have higher education degrees, but only 5 have courses that include knowledge of the environment. Regarding the marketing department, all Companies have this department, but only 5 of them run campaigns intending to direct consumers to purchase water-based varnishes. Regarding the R&D department, only 5 Companies have this department in their units, finally, regarding the percentage of sales of water-based varnish, the one large company that stood out the most, and the other that stood out negatively.

3.3 Certification

There are several types of certifications that Companies that manufacture chemical products can have, but the 2 that will be highlighted in this work are certification by APT [14] and ISO 14001 [15]. As already mentioned, APT [14] is a non-profit organisation that aids its member Companies in several areas, from an economic, legislative, environmental and developmental point of view. ISO 14001 [15] is a non-mandatory certification that involves active audits in member Companies and aims to help Companies identify, prioritise and manage their environmental risks as part of their usual practices. Figure 7 shows the number of companies with APT [14] and ISO 14001 [15] certification. It can be observed only

Fig. 7 Relationship between number and type of Company certifications



20 of the 41 Companies analysed have APT certification, and for 20 of these Companies, only a small proportion have ISO 14001 certification, i.e. of the 41 Companies analysed, only 8 Companies have international w standard certification, and are also APT certified. The lack of certification among many companies implies a gap in their commitment to sustainable practices, as those with ISO 14001 are more likely to implement structured environmental management systems.

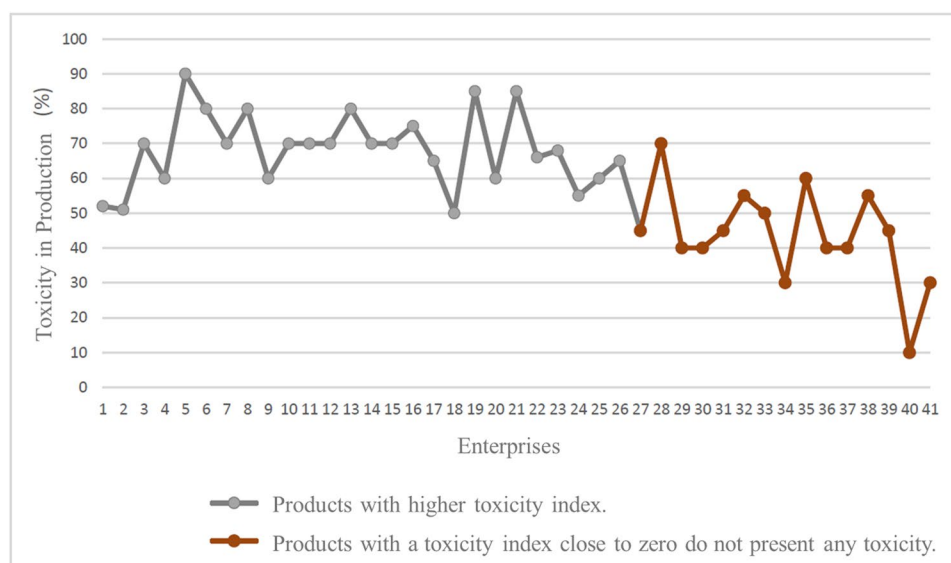
The results presented show that the number of small Companies certified by the ISO 14001 [15] standard and/or by the APT [14] are very small, as only 4 companies out of 20 (20%) have some kind of certification. This low certification rate suggests that many companies may not be actively engaging in sustainable practices, as certifications often serve as a benchmark for environmental responsibility. Regarding the environmental counselling policy, which is a practice that is highly regarded by those responsible for the environment, only 4 Companies have this policy as current practice (10%). This policy is crucial for guiding companies in adopting sustainable practices. The low percentage of companies with such policies further emphasizes the weak link between certification and the implementation of effective environmental strategies. Companies lacking certifications tend to exhibit a low level of environmental commitment, showing inadequate sustainable practices. This reinforces the idea that certifications play a vital role in promoting and ensuring adherence to sustainable practices within the paint manufacturing sector.

3.4 Level of toxicity presented in production and finished products

The proportion of paints with toxic compositions is very high among Companies worldwide. To better understand this issue, a separate question was asked to verify the paint percentage with a high toxicity index produced by each company analysed for the construction industry. Figure 8 shows the percentage of paints with high and low toxicity index for paints used in civil engineering produced by each company. The graph shows that some Companies that present products with the highest toxicity index are consistent with their production of at least 50%, i.e. some 26 Companies that reported a higher production with a high toxicity index produce a significant percentage. However, of the 15 Companies that reported having non-toxic products or products with a lower toxicity index. But 4 of them that reported having non-toxic products or products with a toxicity index close to zero do not present coherence in their information, as these companies have a percentage of toxic products close to 55%, 55%, 60% and 70%, i.e. they fit in the group of products with the highest toxicity index.

When it is talked about paints with a high toxicity index, what it can be done when it can be removed it from where they have been applied (walls, furniture, doors and windows) is not usually mentioned. If there is something harmful removal of the toxic raw material present in the paints when they are removed affects the environment in some way because although it is advisable to remove it with water, the effluent generated by this is harmful if it meets the effluent system, among other concerns. The number of companies concerned with the removal of the paint from the place where it was applied is only 2, i.e. 39 Companies are not concerned at all with the removal of their products at the end of their life cycle.

Fig. 8 Level of toxicity in paint production



3.5 Sustainability

Raising awareness among people to buy products with lower toxicity levels is a great step forward for the environment and helps with sustainability. One way for this to happen is for Companies themselves to help publicise and guide consumers so that they choose products with lower or no toxicity levels. During the interview, only 18 of the 41 Companies analysed have customer counselling methodologies, that is, 23 do not follow this methodology. Only 23 Companies do not have counselling, 16 are small, 5 are medium-sized and 2 are large. To facilitate the verification of sustainable thinking on the part of the Companies, some questions related to the environment and concerns pertinent to the topic were included. A question that could have more than one answer was included, about the priorities of each Company regarding the predominant factor in the selection of a component for paints. As can be seen from Fig. 9a, the predominant factor criteria when occurs the selection of a particular paint raw material. The economic factor was mentioned as relevant by all companies, followed by delivery time with 24 companies, environmental with 14 companies and final experience with 9 companies.

Regarding toxicity, a question was asked to find out at which stage of the product life cycle the Companies had data on toxicity research, and this question also allowed more than one answer. Figure 9b shows the stages in the life cycle of paints where toxicity studies have been carried out. According to the graph in Fig. 9b, the phase with the highest number of toxicity studies is the production phase, with 38 Companies responding in the affirmative. This is followed by the storage phase, with 28 Companies, and finally, the application phase, which is studied by 8 companies. It is important to highlight that Portuguese legislation is very demanding when it comes to the toxicity of chemical products, so these studies are usually carried out frequently to help companies comply with the law when it comes to the emission of toxic products.

Regarding the acquisition of raw materials with less toxic properties or with no toxicity, the question was asked about the importance given by the companies analysed to the acquisition of this type of raw material.

Figure 10a shows that only 19 companies indicated that they attach little importance to the acquisition of raw materials with a low toxicity index, followed by 14 companies that attach medium importance to the acquisition of products with a low toxicity index, and finally 8 companies that show a constant interest in the acquisition of raw materials with a low toxicity index. For products with a lower toxicity index in the new products development, the companies showed a similar pattern to the responses in Fig. 10a, regarding the raw material to be used. Toxicity in paints and varnishes is a problem that has the potential to spread globally. For this reason, there are several national and international laws with limit values for the emission of wastewater, gases and waste [23]. Unfortunately, many companies are not concerned about the pollution they could cause to the environment, as many only comply with the minimum required by law.

Figure 10b shows the level of importance given by companies to reducing global toxicity. Most companies have a low level of concern about reducing the overall toxicity of the paints they produce, i.e. around 21 companies have a low level of concern, 16 Companies have a medium level of concern, and only 3 large companies have a specific, well-parameterised programme to reduce the overall toxicity of the products they produce, and only one company has no concern at all.

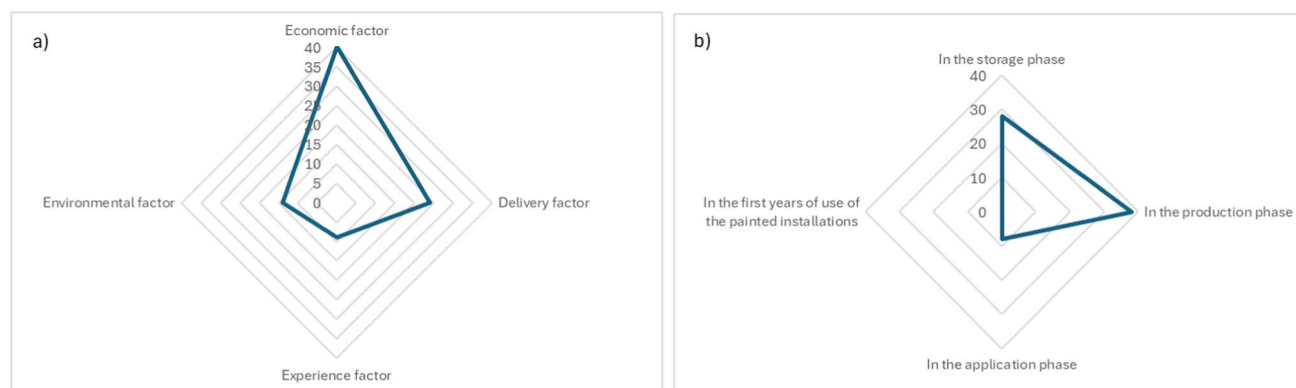


Fig. 9 **a** Relevant criteria when selecting paint raw materials and **b** studies carried out on the toxicity of different paint raw materials

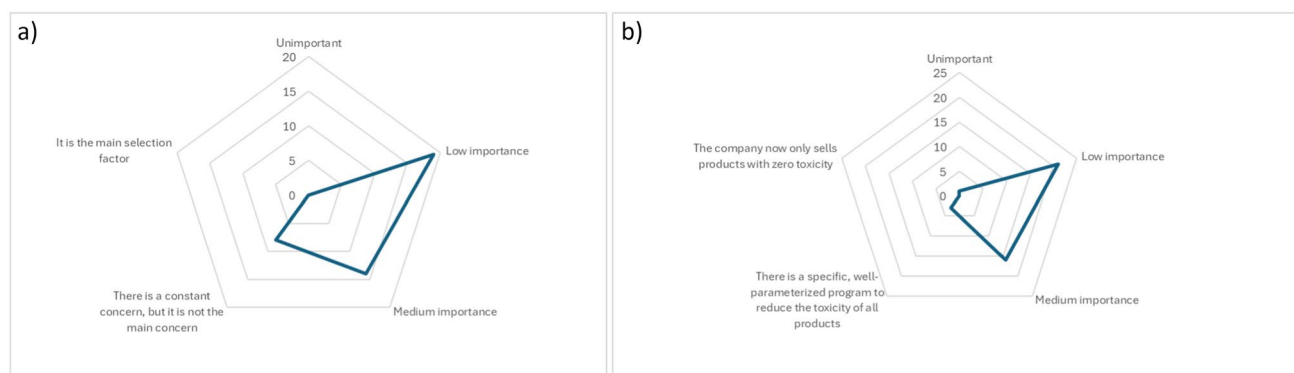


Fig. 10 **a** Level of importance given by companies to the acquisition of raw materials with lower toxic content or zero toxicity and **b** Importance given by the company to the overall reduction of toxicity of its products

3.6 Hypothesis testing

To perform the two types of hypothesis tests, the T-student test and the chi-square test for independent samples were used. To facilitate the handling of the variables, 6 data sets were used. The first 3 data sets contained only environmental data and the percentage of toxicity in the products. The last 3 datasets were also separated by company size but with variables related to the administrative and some technical sectors. Each dataset allows a detailed analysis of the number of small, medium and large companies, with relevant information on each company's certifications, active environmental policies and the predominant factor in each company's raw material acquisition, the existence of sustainable thinking in each company and the percentage of toxic products manufactured.

For the hypothesis tests, a significance level of 5% is considered both in parametric and non-parametric tests. For the Chi-Square test, which is a non-parametric test and is also aimed at qualitative variables, the variables considered are Company size, sustainable thinking, certification and environmental advice policy for customers. Regarding the T-student test for 2 independent samples, which is a parametric test, it aims to verify whether there is any relationship between the groups analysed, comparing the means of each group, these groups being composed of the values of the percentage of toxic products manufactured and the percentage of sales of water-based varnish.

The results of each hypothesis test, both parametric and non-parametric, produced highly significant results (Table 2). Since the assigned significance level was 5%, the results must have values lower than 5% ($p < 0.05$) to be significant. Therefore, the first 2 tests, analysed using the chi-square model for independent samples, yielded results of 0.00017 for Companies with a sustainable mindset and 0.00001 for Companies certified with an environmental consultancy policy analysis. Regarding the T-student test for 2 independent samples, the analysis between the predominant factor variables by the percentage of toxicity in the manufactured products had a p-value of 0.0257, considering the test with the following variables: higher education level of the person responsible for purchasing raw materials with a degree in environmental knowledge, with the percentage of toxicity of the manufactured products, having obtained a p-value of 0.0019. In the last 2 tests, the existence of an R&D department by the percentage of toxicity in the products manufactured and the active marketing department concerning water-based varnish by the sales percentage had results of 0.0012 and 0.00007.

3.7 Critical analysis of the results

Environmental commitment in the chemical industry is extremely important, especially because of the dangers that can arise from limited handling. Knowing that the paint industry tends to produce products with a high toxicity index, this work focused on verifying the environmental performance of paint production in Portuguese industries in the construction area. Then, it is necessary to analyse the relevant information that can directly and/or indirectly contribute to the levelling of the environmental commitment of each company studied, whether small, medium or large companies [24].

In Portugal, there are approximately 85 registered paint manufacturing Companies, ranging from small, medium and large but, as already mentioned, only 41 of these companies agreed to participate. An analysis of the sample

Table 2 Hypothesis testing results

Relationships between variables	Shapiro–Wilk normality test	Average	Standard deviation	T-student test for two independent samples (p-value)	Chi-square test for independent samples (p-value)
Company size					0.00017
Sustainable Thinking					
ATP and/or ISO 14001 certification					0.00001
Environmental advisory policy					
Predominant factor (Environmental and/or Economic)	0.558	49.94	18.266	0.0257	
Products percentage with a high toxicity index		62.24	15.221		
Higher education (Yes or No)	0.558	48.50	15.374	0.0019	
Products percentage with a high toxicity index		65.95	14.884		
Existence of R&D Department (Yes or No)	0.558	41.53	12.883	0.0012	
Products percentage with a low toxicity index		66.62	12.222		
Marketing Department active regarding water-based polish (Yes or No)	0.217	37.13	3.364	0.00007	
Percentage of water-based polish sales		15.88	5.995		

revealed that there was a greater concentration of responses from the northern region, with approximately 22 Companies in the study, followed by the southern region with 10 companies and finally the central region with 9 Companies. Regarding exports, of the 20 small Companies that responded to the survey, only 4 export their products, i.e. this attribute is common among medium and large companies, while in small Companies it is completely limited, with only 20% of small companies exporting their products.

Awareness of paint marketing with a lower toxicity index is essential for a company that has some kind of environmental concern. Some sectors can directly assist in this aspect, such as the marketing department, R&D department, raw material purchasing department and raw material analysis laboratory. In the marketing department, as observed in the results, only 5 Companies do not have a marketing department in their units. However, in terms of their campaigns to encourage consumers to adopt water-based varnishes, this number was extremely low, but specifically: 5 small Companies, 6 medium-sized Companies and 5 large Companies carry out this process, that is, even though the majority of large Companies carry out this consumer targeting with the help of marketing, Companies, in general, demonstrated limited participation in advertising campaigns, intending to encourage the purchase of water-based varnish, given that the high toxicity index of solvent-based varnish is extremely harmful to the consumer. Given the scarcity of multiple case studies conducted in the paint and varnish industries, a study by Cultri [25] was used as a comparison, whereas a multiple case study was conducted in footwear industries in 2 Brazilian cities in the interior of the São Paulo state. According to the author, the use of the marketing department for advertising or as environmental assistance was also very scarce, i.e., some similarities with the Portuguese paint industries can be seen. The sales percentage of solvent-based varnish shows that the lack of Companies active participation ends up guiding consumers to buy the cheapest products, regardless of whether they are harmful to health, and all companies, without exception, have sales of over 50% of the most harmful varnishes, i.e., the most harmful product is the one that sells the most.

Another extremely important sector is the raw material purchasing sector, where the need to make inquiries about the acquisition of raw materials is essential to ensure financial accuracy, quality and less damage to the environment. In the survey, all Companies demonstrated that they carry out inquiries in the raw material market, with the vast majority using the systematic consultation model, knowing that this model is the most complete and has the lowest rate of problems with quality, delivery time and lower price. In the study by Cultri [25] some companies already purchase less harmful raw materials for the manufacture of their products, carrying out inspections upon receipt of their orders, in other words, very similar to what happens in some Portuguese paint manufacturing industries.

This work also focused on understanding the level of education of the personnel responsible for purchasing raw materials in each company, and the most striking thing is that only 50% of the companies have an employee responsible with a degree in some field with average knowledge of the environment, and 32% do not even have any higher education. This shows that many companies do not see the need for a person with theoretical skills to be able to have a more critical attitude in the selection of raw materials and to be able to make decisions that may be harmful to the environment, that is, with a higher toxicity index. It is important to highlight that all those responsible for purchasing raw materials in large companies have at least a degree in some area of knowledge, and only one medium-sized company still has a person responsible for purchasing who does not have a degree, but who is currently taking a higher education course. Therefore, all those who are responsible for the purchasing area and do not have any training are from small companies. In the study by Cultri [25], the main reason why the companies analyzed by the author did not perform or performed environmental actions incorrectly was the lack of information on the subject, that is, the lack of people with specific knowledge about the environment, that is, what is currently happening in most small companies, with the absence of a person with a higher education degree with sufficient knowledge about the environment. After purchases are made, the reception of raw materials is important concerning the packaging quality and the product expiration date, and almost all companies have this analysis. Only 3 small companies do not consider this analysis necessary.

However, concerning the raw materials laboratory analyses, only 20 companies have this attribute, that is, only 20 Companies analyze in detail whether the raw material received is in conditions to be used, thus enabling greater control over the rate of problems in production, about the raw material. Another important department that was highlighted in this work was the R&D department, but only 14 companies have this department, most of which are large, although some medium and small companies also have a R&D department. This shows that most of the companies in this study are not committed to developing research regarding the development of new products in the paints area, and this development may be environmental, economic or technological. However, compared with the study developed by Cultri [25], where most of the footwear industries analysed by the author demonstrated that research was deeply rooted in their units, but unlike this study, it did not allow for a direct reduction in the production of polluting products, even if a footwear industry has less toxicity in its production.

Comparing Portugal with other countries in terms of raw material use, the sustainable coatings industry is making significant progress in several countries, with notable differences compared to Portugal. In India, for example, recent developments focus on bio-based binders such as acrylate epoxidised linseed oil (AELO) for paint formulations, demonstrating a shift towards sustainable alternatives that reduce reliance on petrochemical-based resins [26]. Similarly, in China, there has been a growing emphasis on reducing toxic emissions, with companies increasingly adopting water-based inks and coatings, which significantly cut down on volatile organic compounds (VOCs) [27]. These practices align with global trends pushing for greener, more eco-friendly paint production.

In contrast, Portugal's paint industry, while progressing, still faces challenges in adopting these innovations at scale. Although some companies are beginning to integrate sustainable practices, such as the use of less toxic raw materials and water-based solutions, their efforts remain limited, especially within smaller enterprises. In Peru, significant progress is being made with eco-friendly paints derived from local resources like nopal (*Opuntia ficus*), which are positioned as sustainable alternatives with minimal environmental impact. This contrasts with the more conventional approaches in Portugal, where eco-friendly paints are still not widespread. Companies in Peru are focusing on circular economy principles by reusing waste materials to create eco-friendly products, setting an example of innovative, localized solutions that have yet to be fully explored in the Portuguese market [28].

Australia, on the other hand, is leading with a push towards both bio-based and functional pigments for wood coatings, combining aesthetic and protective qualities. Studies there have utilized natural pigments, such as turmeric, to create bio-based paints, reflecting the country's commitment to integrating sustainability into both product development and industrial practices [29]. Similarly, Italy has advanced in using natural and functional pigments, focusing on sustainable coloring techniques such as turmeric-based pigments for wood coatings, further highlighting the global shift towards bio-based alternatives [30]. The success of these initiatives highlights the gap between Australia, Italy, and Portugal, where the adoption of bio-based alternatives in paint manufacturing is still emerging but not yet fully integrated.

Certifications, whether carried out by the Portuguese Paint Association (APT) or by the ISO 14001 standard, are quite common in paint and varnish manufacturing Companies, with 20 Companies certified by APT, out of the group of forty-one studied, spread across the North, Center and South regions. All companies certified by the ISO 14001 standard are also certified by APT. These certified companies demonstrate more elaborate thinking, environmentally speaking, since most of them have an active marketing department and an R&D department, in addition to having analysis laboratories that allow for better inspection of the raw material. Through the results obtained, it was possible to analyse that the production with some toxicity is very common in the paint industry since all the Companies that participated in the study showed that they produce paints with some toxicity, even if in a minimal percentage. One company produces the highest score of toxic products of 90% for civil construction, and on the other hand, the lowest score is 10% of toxic products for civil construction. In comparison the study by Wang [31], which analysed in more detail the toxicity presented by house paint through volatile compounds emitted by the application of paints in indoor environments, showed that the solvent is extremely dangerous, both in the paint manufacturing phase and in the application itself, even with water-based paint, whether wall paints or varnishes for wood and metal furniture, there is some toxicity present, in a much smaller quantity, but it exists. Therefore, the production of toxic products by paint companies is real, and it will probably not end in the short-term but concerning the sustainability and eco-efficiency of the products, changing the solvent for water is the most appropriate.

In another study, Alencar Junior et al. [32] presented a bibliometrics study on the theme of industrial sustainability in architectural paints. They analyzed 773 international scientific documents from January 1985 to November 2019 and most documents are focused on the study of new paint compositions, which are obtained from the substitution of toxic substances, observing sustainability criteria in their development and testing; which indicates that there is also a need to diversify research approaches. There was little presence of documents dealing with architectural paintings; few publications were found addressing the subject, which configures a gap in the literature related to this field of research. None publications cited here refer to eco-friendly practices in paint manufacturing industries focused on certification, sales and management sectors as mentioned in this study.

In this study, it can be generally seen that all the Companies that reported in the questionnaire having a production with more toxic signs have a production in which the products, in percentage, present significant toxicity, that is, greater than 50%. On the other hand, the companies that reported having production with zero or almost zero toxicity showed that this is not true, as they have higher sales percentages of harmful products, 70% of products with high toxicity, 60% and finally 55%. Thus, showing the contradictions that the Companies have in their answers to the questionnaire. This reveals another problem: lack of knowledge and seriousness in defining their products. Some questions were included in the questionnaire to identify whether the companies that participated in the survey had a sustainable mindset, where

the environment is remembered consistently, and not just because of the imperative of the legislation applicable in Portugal. Avesani [33] mentions that sustainable development is a set of things that contribute directly and indirectly to the environment, and these sets of things enable sustainable thinking used in responsible companies. However, the result was quite worrying, because of the 41 companies analysed, only 8 have a mindset focused on sustainability, and most of these companies are medium and large-sized, that is, only 3 out of 20 small Companies (15%) have this type of thinking. This is an extremely worrying factor given the number of small Companies in Portugal. It is also important to note that there are small companies that think about the environment, but in most companies, this mindset does not exist or is not consistent. Regarding the study by Scruggs [34], in which he referred to weakened sustainability because of the type of industry, one of the main reasons was the lack of commitment of the company in question, with the lack of internal advice and a well-founded policy, having reported an indicator of economically weak sustainability. In the advice directed at the consumer to adhere to products with a lower toxicity index, the results are well below expectations, with more than 50% of the Companies not practising this method.

Unfortunately, in this work, it was observed that the economic factor takes priority over all others in the paint and varnish manufacturing industries and many of the companies only do what is necessary to comply with the country's environmental legislation, which is, they do not think more deeply about the toxicity that paints can represent for the environment. Based on the responses analysed from the sustainability group, this behaviour is perfectly visible.

The hypothesis tests were chosen to directly assist in the specific objectives of this study, that is, all the variables used for the tests were removed and shaped through the information provided by the companies' responses to the questionnaires, with each variable being constructed by sets of answered questions, to obtain relevant relationships in the calculations. In the hypothesis tests performed, as already mentioned, all obtained significant results, that is, all with a p-value lower than 0.05.

Regarding the relationship between the size of companies and sustainable thinking, it was possible to verify that there is indeed a relationship between size and thinking focused on the environment, that is, that medium and large companies are more sustainable thinking. The Chi-Square test showed that this relationship between size and sustainability is relevant, placing small companies as those that think least about the environment, with exceptions.

The objective of the variables certifications [14, 15] and environmental advice policy was to analyse whether there was any statistical relationship between certified companies having an established policy of environmental advice directed to the consumer of the products produced by each company. It was found that this relationship exists, given that the result of the hypothesis test provided a p-value equal to 0.00001, that is, the null hypothesis was rejected, obtaining an extremely relevant significance, thus being able to say that statistically, this relationship exists. The variables' predominant factor in the purchase and products manufactured percentage with a high toxicity index were studied regarding the T-student test. This study aimed to analyse whether the environmental factor presence, chosen by a company for the raw material selection, is positively influenced by the products' percentage with a low toxicity index. As can be seen through the hypothesis test results, the predominant factor proved to be statistically fundamental for the increase or decrease in the percentage of toxic products, that is, when the environmental factor is used to select a given component for paints, the companies showed a lower production percentage of toxic products.

Regarding the education level of the personnel responsible for the raw materials acquisition for each company, a parametric hypothesis test was performed with the following variables: higher education level in courses with knowledge focused on the environment and percentage of manufactured products with a high toxicity index. This test was to analyse whether the education level of the personnel responsible for purchasing raw materials statistically influenced the percentage of the products with a high toxicity index. This test demonstrated that there is indeed a very significant relationship, that is, based on the result, it can be stated that in the companies analysed that have a person responsible for purchasing raw materials who has a degree in some course with knowledge related to the environment, there is a preference for manufacturing products with a lower toxicity index, in terms of percentage of their total production. Regarding the existence or not of an R&D department, Pereira and Sequeira [35] reported how important research is for the business sector, showing that the existence of this department tends to make a difference in the market, regardless of the Company type and size. Then, 2 variables were separated: the existence of the R&D department and the percentage of products with a lower toxicity index, to analyse whether companies that have this department tend to produce fewer products with a high toxicity index. This relationship is statistically correct, as the results of the T-student test showed that companies that had these departments produced fewer products with a high toxicity content.

Regarding the use of the marketing department in the promotion of water-based varnishes, the hypothesis test, also parametric, was used to analyse whether the sales percentage of these varnishes was related to the existence and efforts of the marketing department, directing consumers to adopt water-based varnish, which is much less harmful

than solvent-based varnish. This analysis also obtained significant results, showing that when the marketing department carries out its campaigns responsibly and intelligently, consumers are directed to adopt the indicated products, that is, the companies that indicated that they had active marketing departments regarding the promotion of water-based varnish, really increased the sales of these varnishes significantly, even though the cost to the customer is much higher than that of solvent-based varnish. Unfortunately, many companies use marketing incorrectly, as it also directs consumers to adopt products that are not beneficial to their health. Ihnatenko [36] refers exactly to this, showing when marketing is sometimes used incorrectly and can direct a significant number of people to the misuse of environmentally unsuitable products. In general, it can be said that the companies analyzed can improve in the environmental aspect, but some companies in this study stood out positively, with 17 companies presenting an acceptable environmental commitment, with emphasis only one Company, which presents sustainable thinking in every sense, having all the necessary departments, including marketing department, R&D department, raw material reception analysis, raw material analysis laboratory and, mainly, the lowest percentage of products manufactured with a high toxicity index, being a large Company and the best environmentally speaking. On the other hand, 24 Companies, that is, approximately 59% of the companies analysed, demonstrated a limited environmental commitment, most of them small companies demonstrated the worst environmental performances in this study being highlighted in 3 Companies. These did not have any kind of environmental thinking or departments that could directly support the departments that could directly support environmental sector, as these 3 small companies are the the largest relative amount of products with a high toxicity index.

As one of the solutions to improve the environmental thinking of companies, Spreafico et al. [37] proposed to implement a prospective Life Cycle Assessment (LCA) to evaluate eco-design solutions, including ideas and prototypes. They emphasise the use of patent literature in building the foreground inventory for prospective LCA. Data extracted from patents can improve the quality and comparability of data in LCA. They also mention the importance of evaluating specific functions of products throughout their life cycle to make sustainable decisions about the use of certain raw materials in the manufacture of their products. The proposed method can help to reduce uncertainties associated with traditional LCA approaches and can provide significant insights into product development directions using patent analysis.

4 Conclusions

This study highlights a need for improved environmental commitment among Portuguese paint manufacturers to adopt eco-friendly practices in their manufacturing process to meet the 17 Sustainable Development Goals. The main conclusions are:

- The study reveals that a significant portion of Portuguese paint and varnish manufacturers exhibit a low level of environmental commitment. Specifically, 59% of the companies analyzed demonstrated limited commitment, lacking the necessary departments and sustainable practices to adapt their products to environmental standards effectively.
- The findings indicate that smaller companies are particularly lacking in environmental commitment, with only 3 out of 20 small companies showing a significant commitment to sustainability. In contrast, medium and large companies tend to have a more evolved perspective on environmental issues, although economic factors still dominate their decision-making processes.
- The lack of commitment to sustainability not only affects the environment but also poses risks to the workforce. Many companies disregard the hazardous conditions their employees face, which is a significant concern for public health and safety.
- Necessity for legislative measures that encourage consumers to opt for healthier and more sustainable products. This is crucial for fostering a market that prioritizes eco-friendly options, even if they come at a higher cost.
- All companies studied, regardless of size, needs to adhere to minimum sustainability criteria.
- There is a necessity for training programs aimed at improving the knowledge and skills of employees responsible for purchasing raw materials. This can lead to better decision-making regarding environmentally friendly options.
- Companies should leverage their marketing departments to promote eco-friendly products effectively. This includes highlighting the benefits of water-based varnishes and other less harmful alternatives to consumers.
- The paint manufacturing sector is complex and multifaceted. A more robust focus on environmental considerations is essential, not only within the paint and varnish industry but across the broader industrial landscape.

Some recommendations can be followed to enhance sustainability in the paint manufacturing sector. They are:

- The study recommends that paint manufacturers, especially smaller companies, should adopt a stronger commitment to sustainability. This includes integrating environmental considerations into their business models and operational practices to improve their overall environmental impact.
- It emphasizes the need for legislative measures that incentivize consumers to choose healthier and more environmentally sustainable products. This could involve policies that promote eco-friendly products, even if they come at a higher cost.
- The research highlights the importance of educating consumers about the benefits of eco-friendly paints. Improved marketing strategies should be developed to raise awareness and encourage the adoption of less toxic products, such as water-based paints.
- Collaboration among manufacturers, suppliers, non-governmental organizations, and community groups to promote sustainable practices. This collective effort can lead to more effective implementation of eco-friendly initiatives.
- Specific policies should be included to encourage investment in research and development in the coatings industry. Government subsidies could support companies that carry out R&D to develop more sustainable formulations, while tax incentives could be granted to those that adopt environmental certifications, thereby strengthening environmental awareness within the sector. These measures would help accelerate innovation and the transition to eco-friendly practices.

For future research, it would be ideal to expand the sample to include a larger number of companies to increase the representativeness of the results and analyse the adoption of sustainable practices in the paint industry. In addition, it would be relevant to examine companies' innovation development through the evaluation of patents to better understand the impact of these innovations on environmental sustainability.

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Declarations

Ethics approval and consent to participate The research was ethically approved by the Ethics Committee of CIDEM, ISEP, School of Engineering, Polytechnic of Porto. Before participation, all participants were duly informed of their rights and responsibilities and provided explicit written consent. The study was conducted in agreement with the guidelines governing research involving human participants, as outlined by the Ethics Committee of the CIDEM, ISEP, School of Engineering, Polytechnic of Porto.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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References

1. Yang J, Zeng Y. Sustainability: design, making, and technologies. *J Integr Des Process Sci.* 2022;24(2):1–3. <https://doi.org/10.3233/jid200021>.
2. Loosemore M, Forsythe P. Sustainable construction technology adoption. In: Tam VWY, Le KN, editors. *Sustainable construction technologies*. Oxford: Butterworth-Heinemann; 2019. p. 299–316. <https://doi.org/10.1016/B978-0-12-811749-1.00009-2>

3. Briggs TA, Uzoma SM. Development of optimization models for the productive capacity of paint manufacturing company to maximize profit. *Intern J Eng Trends Technol*. 2019;67(10):54–7. <https://doi.org/10.14445/22315381/IJETT-V67I10P210>.
4. Sorokin AE, Bulychhev SN, Gorbachev SI. Environmental impact of paints in high-tech production. *Russ Engin Res*. 2019;39:816–9. <https://doi.org/10.3103/S1068798X1909020X>.
5. Mohsin MM, Beach T, Kwan A. Public perceptions of urban sustainable challenges in developing countries. *Trans Eco Environ*. 2017;226(10):131–40. <https://doi.org/10.2495/SDP170121>.
6. Michalak J, Bartosz M. Understanding sustainability of construction products: answers from investors. *Contract Sellers Build Mater Sustain*. 2022;14(5):3042. <https://doi.org/10.3390/su14053042>.
7. Ciacci L, Vassura I, Catalano F, Simoncelli A, Moretti F, Passarini F. Sustainability in building and construction: LCA of 21 mural paints. *Key Eng Mater*. 2022;919:227–35. <https://doi.org/10.4028/p-yd1rz1>.
8. Anand A, Sinha AK, Tak FI, Tak AA, Khan RA. A new approach for sustainability-based material selection model of toxic chemicals in manufacturing domain. In: Govindan K, Kumar H, Yadav S, editors. *Advances in mechanical and materials technology*. EMSME 2022. Lecture notes in mechanical engineering. Singapore: Springer; 2022.
9. Ncube A, Mtetwa S, Bukhari M, Fiorentino G, Passaro R. Circular economy and green chemistry: the need for radical innovative approaches in the design for new products. *Energies*. 2023;16(4):1752. <https://doi.org/10.3390/en16041752>.
10. Faísca CM, Moruno FM. From raw materials to where the industry happens. Patterns of industry location in the Portuguese cork manufacture: 1880–1980. *Rúbrica Contemporânea*. 2023;12(23):179–201. <https://doi.org/10.5565/rev/rubrica.273>.
11. da Faria MJS, Oliveira IMM, Figueiredo J. Sustainability as a puzzle will be a Portuguese Utopia. *J Econ Finance Manag Stud*. 2024. <https://doi.org/10.47191/jefms/v7-i5-54>.
12. Bento AI, Ferreira LM. An exploratory study on the implementation of social sustainability practices in Portuguese industries. In: Silva FJG, Ferreira LP, Sá JC, Pereira MT, Pinto CMA, editors. *Flexible automation and intelligent manufacturing: establishing bridges for more sustainable manufacturing systems*. FAIM 2023. Lecture notes in mechanical engineering. Cham: Springer; 2024.
13. Alves W, Silva Â, Rodrigues HS. Green practices as a path towards the sustainability: evidence from Portuguese companies. *Bus Syst Res Int J Soc Adv Innov Res Econ*. 2020. <https://doi.org/10.2478/BSRJ-2020-0012>.
14. Associação Portuguesa de Tintas. Regulamentação. Disponível em: <https://aptintas.pt/regulamentacao/>. Accessed 17 Oct 2023.
15. International organization for standardization. ISO 14001:2015 environmental management systems - requirements with guidance for use. Geneva, 2015.
16. Loureiro A, Monteiro S, Guzmán BA, Ribeiro VPL, Lemos K. What are the drivers behind Portuguese companies' reporting on sustainable development goals? *Esic Market*. 2024. <https://doi.org/10.7200/esicm.55.354>.
17. Guerreiro MS, Susana O, Alexandra B, Rute SA. The Disclosure of Environmental Indicators in the Portuguese Paper Industry and Society 5.0, 18th Iberian Conference on Information Systems and Technologies (CISTI), Aveiro, Portugal. 2023; 1–7, <https://doi.org/10.23919/CISTI58278.2023.10211589>.
18. Acton C, Miller RL, Fullerton D, Maltby J. SPSS for social scientists. Basingstoke: Palgrave Macmillan; 2009. p. 298–304.
19. MacFarland TW. Student's t-test for independent samples. In: MacFarland TW, editor. *Introduction to data analysis and graphical presentation in biostatistics with R*. SpringerBriefs in statistics. Cham: Springer; 2014.
20. McHugh ML. The Chi-square test of independence. *Biochem Med (Zagreb)*. 2013;2013(23):143–9. <https://doi.org/10.11613/BM.2013.018>.
21. Janković S. Tests for comparison of two groups: student's T-test, Mann-Whitney U-test and Chi-square test. *Int J Biomed Healthc*. 2022;10(2):134–6. <https://doi.org/10.5455/ijbh.2022.10.134-136>.
22. Wang D, Yu H, Shao X, Yu H, Nie L. Direct and potential risk assessment of exposure to volatile organic compounds for primary receptor associated with solvent consumption. *Environ Pollut*. 2018;233:501–9. <https://doi.org/10.1016/J.ENVPOL.2017.10.009>.
23. Burghardt TE, Pashkevich A, Żakowska L. Influence of volatile organic compounds emissions from road marking paints on ground-level ozone formation: case study of Kraków, Poland. *Transp Res Proc*. 2016;14(714):723. <https://doi.org/10.1016/J.TRPRO.2016.05.338>.
24. da Silva RV, Teixeira N. Environmental business strategy: the Portuguese case. *Bus Strat and the Environ*. 2008;17(3):208–18. <https://doi.org/10.1002/BSE.512>.
25. Cultri CN. Environmental actions articulated in sustainability: a study of multiple cases in the footwear industry. Master Thesis. UNESP, Bauru, São Paulo. 2008.
26. Singh M, Prakash B, Lodhi R, Kulshreshtha A, Manik G. Eco-friendly ink formulations with acrylate epoxidized linseed oil binders: balancing performance and sustainability. *Prog Org Coat*. 2025;204:109199. <https://doi.org/10.1016/j.porgcoat.2025.109199>.
27. Tian X, Lv S, Li J, Zhang J, Yu L, Liu X, Xin X. Recent advancement in synthesis and modification of water-based acrylic emulsion and their application in water-based ink: a comprehensive review. *Prog Org Coat*. 2024;189:108320. <https://doi.org/10.1016/j.porgcoat.2024.108320>.
28. Muñoz FBS, Céspedes A/M/S, Cueva R, Jaime Y, Porras VZQ. Preparation Of Eco-Friendly Painting Based On Dairy Products For Masonry And Wooden Walls, 3 rd LACCEI International Multiconference on Entrepreneurship, Innovation and Regional Development – LEIRD, Cajamarca, Peru. 2023; <https://doi.org/10.18687/LEIRD2023.1.1.446>.
29. Haji A, Naebe M. Cleaner dyeing of textiles using plasma treatment and natural dyes: a review. *J Clean Prod*. 2020;265:121866. <https://doi.org/10.1016/j.jclepro.2020.121866>.
30. Calovi M, Rossi S. Exploiting turmeric's coloring capability to develop a functional pigment for wood paints: sustainable coloring process of polyamide 11 powders and their strengthening performance. *Coatings*. 2024;14(7):858. <https://doi.org/10.3390/coatings14070858>.
31. Wang D, Nie L, Shao X, Yu H. Exposure profile of volatile organic compounds receptor associated with paints consumption. *Sci Total Env*. 2017. <https://doi.org/10.1016/J.SCITOTENV.2017.05.247>.
32. Alencar Junior AA, Delesposte JE, Mainier FB, Mattos LV. Industrial sustainability in architectural paints: a bibliometric research. *J Intern J Innov Techn Manag*. 2023. <https://doi.org/10.1142/S0219877023500037>.

33. Avesani M. Sustainability, sustainable development, and business sustainability. *Life Cycle Sustain Assess Decis Mak Method Case Stud.* 2020. <https://doi.org/10.1016/B978-0-12-818355-7.00002-6>.
34. Scruggs CE. Reducing hazardous chemicals in consumer products: proactive company strategies. *J Clean Prod.* 2013;44:105–14. <https://doi.org/10.1016/J.JCLEPRO.2012.12.005>.
35. Pereira A, Sequeira J. Do R&D and marketing departments perceive innovation fundamentals through the same lenses? *Int Eng Manag Conf.* 2008. <https://doi.org/10.1109/IEMCE.2008.4617993>.
36. Ihnatenko R. Ecological trends of modern marketing activity. *Ekonomika Finansi Pravo.* 2022;2:25–9. <https://doi.org/10.37634/efp.2022.2.5>.
37. Spreafico C, Landi D, Russo D. A new method of patent analysis to support prospective life cycle assessment of eco-design solutions. *Sust Prod Consump.* 2023;38:241–51. <https://doi.org/10.1016/j.spc.2023.04.006>.

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