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*Review*

# Using Citizen Science to Manage Odour Emissions in National IED Plants: A Systematic Review of the Scientific Literature

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**Abstract:** The potential of citizen science to address complex issues has been recognized since the 1990s. However, the systematic integration of public opinion in research has been developed only recently, thanks to the spread of questionnaire web-based surveys and artificial intelligence techniques for data elaboration. Starting from this point, we decided to investigate the literature published in Scopus during the decade 2013–2023, regarding citizen science applications for environmental purposes. More specifically, the focus of our study was to evaluate citizen science's benefits and limitations for managing odour emissions in national industrial plants, as well as to discuss the potential integration of a participatory approach in such a field. In fact, according to European Directive 2010/75/EU, the integrated environmental permits released to reduce industrial pollution should also encourage strong public participation. In this systematic review we first applied the principles of PRISMA methodology to select the most significant papers. Then, we discuss the results of 14 publications, through bibliometric statistics and meta-analysis. Only three of them were discovered to have a specific focus on odour emissions. Overall, we pinpointed the main advantages and limitations of citizen science applied to odour pollution management, to open the door for further research.

**Keywords:** citizen science; participatory approach; odours; environmental permits; industrial plants

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## 1. Introduction

Citizen science can be defined as the direct participation of the public in research to increase scientific knowledge. More in detail, it is aimed at involving everyone (without considering his/her specific education or professional background) in collecting, assessing and elaborating data to promote innovation. Its first appearance has been traced in the issue published in January 1989 by the MIT Technology Review for environmental purposes [1].

In recent years, citizen science has definitely spread out. Just to illustrate this concept, several authors have considered the potential of public engagement to assess and monitor biodiversity [2,3]. Others have discussed the use of public opinion for land [4–6] and climate change management. Moreover, participatory approaches in research projects have been encouraged by artificial intelligence techniques, allowing quicker data elaboration than traditional algorithms.

At an international level, citizen science was first addressed in 1998 by the UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention), signed by 47 States [7].

In recent years, no specific regulations have been published about the public's participation in research, but some well-established networks were created. For example, the European Citizen Science Association (ECSA) was set up in 2014 [8], while in the U.S.A. the Citizen Science Association (CSA) [9] was established with the aim to support a participatory approach in both natural and social sciences. Moreover, the Horizon 2020 Program was designed with a specific part entitled "Science with and for Society" [10]. Finally, the

Citizen Science Global Partnership has brought together all of the networks seeking to promote citizen science for global sustainability since 2017 [11].

Public participation in environmental issues has been clearly addressed by the European Directives about environmental authorizations to develop territorial plans/programmes (Directive 2001/42/EC [12]) or construction and industrial projects (Directive 2011/92/EU [13]). Focusing the attention on the emission management from industrial plants, it is worth noting that in Directive 2010/75/EU (i.e., Industrial Emissions Directive—IED [14]) the legislator required the public's participation during the whole process aimed at realising the Integrated Environmental Authorization (IEA).

Nowadays, European operators carry out industrial activities, according to the conditions established in their IEA, taking into account the *Best Available Techniques* (BAT) stated for each IED sector [15,16]. Furthermore, in Italy, IEAs are released according to Legislative Decree n.152/2006 [17], Title III-bis Second Part. They are generally valid for ten years, unless the operator has already received an ISO 14001 certificate [18] or an environmental declaration according to the Eco-Management and Audit Scheme (EMAS) [19,20]. In such cases, the deadline of any IEA can be extended up to 12 or 16 years (respectively).

As regards the installations of national concern, the Institute for the Environmental Protection and Research (Italian acronymous "ISPRA") has been entitled to elaborate a Monitoring and Control Plan (MCP) since 2014. Such a document is put into practice by operators. It is aimed at preventing the environmental impacts of industries through an integrated monitoring of several aspects, according to the site-specific conditions of installations [21].

Among the environmental aspects, odour emissions are considered a matter of serious concern in many industrial contexts (e.g., refineries, chemical plants, landfills, etc.). In fact, odours have been accounted for as a source of headaches, nuisance, diseases of the neurologic system, etc., according to the exposure [22,23]. Hence, following the BAT Conclusions related to some industrial sectors, in several MCPs odour monitoring has been required of operators.

Even though instrumental methods have been considered to provide more trustworthy results of environmental impacts, we decided to investigate the opportunity to integrate citizen science into the whole process of assessment. In fact, in Europe, a few recent experiences have highlighted a new way to tackle odour pollution, through public involvement: for instance, the Distributed Network for Odour Sensing, Empowerment and Sustainability (D-NOSES) project [24] and the Odor.net application, developed in Italy by Arpa Marche [25].

More specifically, this study investigates the scientific literature about the environmental applications of citizen science and tries to give an answer to the following questions:

1. "What could be the advantages of citizen science in the odour impact assessment?"
2. "To what extent could citizen science limit the odour impact assessment?"
3. "How could operators and policy makers successfully integrate public engagement in odour monitoring at industrial sites?"

All the above-mentioned questions will be discussed with reference to the framework defined by the Directive 2010/75/EU (so-called IED Directive) for the installations of national competence. In fact, we aim at highlighting the current state of the art on citizen science applied to the industrial odour pollution, to understand if/how to encourage it among operators of large industrial plants.

Hence, the article is organized as follows. In the next section, a narrative focus on odour monitoring in industrial sites subjected to Directive 2010/75/EU provisions is provided. Then, Section 3 illustrates materials and methods which were employed for this systematic review, while Sections 4 and 5 pinpoint the main results of our study (bibliometrics and meta-analysis, respectively). Finally, Section 6 discusses the achieved results and Section 7 concludes the paper, addressing hypothetical research in this field.

## 2. Monitoring Odours in National IED Installations

According to the ISO 5492 Regulation [26], odour is as an organoleptic attribute, perceived when sniffing specific volatile substances. A great variety of theories involving vibrational energy levels, intermolecular interactions, and molecular features have been proposed to explain how the human olfactory system detects and discriminates odours [27]. However, for the stated purposes, it is sufficient to consider odours as the sensations caused by gaseous mixtures, depending on the following:

(a) the chemical composition and quantity of the gases released and interacting with the human olfactory system;
(b) the human receptors' sensitivity, which depends on physiological factors, age or sex, persistent exposure and social factors [28].

In industrial sites, odours mainly result from the interaction of sulphur compounds (e.g., sulphides, mercaptans), nitrogen compounds (e.g., ammonia, amines) and volatile organic compounds (e.g., esters, acids, aldehydes, ketones, alcohols) [29,30]. Such substances can be related to the storage of odorous raw materials, to the presence of facilities for wastewaters as well as to the collection and storage of solid waste. Ambient temperature, time of storage and weather conditions can also influence the amount of odours emitted [31,32].

Liu et al. [32] reported odours as the second of the biggest universal threats. In fact, people living near industrial facilities can suffer from annoyance, i.e., the psychological symptom which refers to poor quality of life or negative mood states. In addition to this, headache, nausea and sleeping disturbances have been found to be typical physical reactions to odour exposure [33]. However, as reported by [34], the toxic effects of odours on public health can be more severe in cases of cancerogenic compounds and strong exposures.

In European countries, some BAT Reference documents (BREFs) have identified strategies and technologies aimed at both reducing the odour impact and monitoring it [35,36]. They are considered the "best techniques" to address such environmental issues that are "available" on the market at reasonable costs for each sector, unless new data demonstrate that other techniques can better address the problem in a sustainable way. In national IED installations, BAT addressing odour emissions can include first the isolation of odorous sources with barriers, in order to collect and treat the conveyed gases. Then, odour treatment technologies can be selected among physical, chemical and biological ones [37,38].

However, BREFs/BAT Conclusions do not consider the site-specific conditions of installations, thus requiring the integration with national/regional legal frameworks in such a field. In Italy, after the introduction of the article 272-bis D.Lgs. 152/2006 [17], several regional guidelines on odour emissions were published to promote a systematic approach to such an environmental issue [39–41].

Hence, in industrial plants subjected to the provisions of Directive 2010/75/EU [14], odour monitoring generally requires the implementation of the following phases:

1. Identifying the odour sources (e.g., waste dumps, hydrocarbon tanks, etc.);
2. Identifying the potential receptors (e.g., residential and religious buildings, schools, etc.) of the odour emissions;
3. Evaluating the odour impact (according to a quantitative scale in odour units).

The first phase can be carried out through the analysis of official documents produced by operators and Public Administration (e.g., cartography, technical reports on industrial processes, etc.) and BAT Conclusions regarding the specific sector. In some cases, the existing maps of odour sources can be updated with a field inspection, involving, whether necessary, the use of drones or LIDAR platforms. For example, unmanned aerial vehicles could be particularly useful to map the sources containing cancerogenic substances, thus reducing the direct exposure of operators in the field [42].

During the second phase, looking in previous scientific studies (e.g., public health surveys, technical analyses, etc.) or collecting and elaborating citizen complaints could be some good strategies to identify potential receptors. In most cases, the dispersion models of odours (e.g., AERMOD, Calpuff, etc.) can provide information on civil and residential buildings, which could suffer from the odour impact, through the analysis of emission rates [43–45].

Finally, the third phase involves the quantitative assessment of the odour impact [46]. In most cases, dynamic olfactometry has been considered the reference method to evaluate odour emission rate (OER), starting from the assessment of the odour concentration emitted by a selected source. It requires evaluating the geometry and the nature of the emission source, collecting gas samples, assessing the chemical composition of odours, sniffing the gaseous samples (after dilution with neutral air) through an expert panel and comparing the odour impact with benchmark values. As observed by [47], during the sniffing analysis of gases taken from refineries, panellists are directly exposed to undefined chemical risk, due to the presence of toxic pollutants in odorous samples.

Hence, research has also moved forward to the dimension of e-noses [48,49]. E-noses generally include advanced sensors and software components, allowing the monitoring of odours continuously or/and in limited accessible areas of the industrial sites. Data elaboration can be performed remotely, thanks to wireless systems sending information to a control device (e.g., a laptop) [50]. Major applications have been related to the WWTPs [51,52], landfills [53], animal farms [54] and petrochemical plants [47,55].

In Table 1 an overview on the general state of the art on odour monitoring in national IED installations is provided.

**Table 1.** Monitoring odour emissions in national IED installations.

| Phase | Strategies |
|---|---|
| 1. Identifying the odour sources | (a) Analysis of official documentation produced by operators and Public Administration;<br>(b) Looking in the BAT Conclusions for the sector of interest;<br>(c) Field inspection;<br>(d) Mapping the sources containing cancerogenic substances through unmanned aerial vehicles (e.g., drones); |
| 2. Identifying potential receptors | (e) Referring to previous scientific studies;<br>(f) Analysis of the citizen complaints;<br>(g) Using dispersion models of air pollutants (e.g., AERMOD, Calpuff); |
| 3. Evaluating the odour impact | (h) Collecting odour samples;<br>(i) Assessing the chemical composition;<br>(j) Sniffing analysis through an expert panel;<br>(k) Comparing results with benchmark values;<br>(l) E-noses. |

## 3. Materials and Methods

In systematic reviews, scientific papers are collected and assessed to provide answers to specific objectives, according to a transparent and reproducible pathway [56]. Most of the systematic reviews reach new conclusions from scientific articles indexed in Scopus, Web of Science, PubMed, etc., which are considered to be valuable databases at an international level [57]. In fact, the publications indexed in one of those databases are generally subjected to a strict and double peer-review process, aimed at preserving a high research quality.

For this study Scopus was selected as the initial database. As reported by [58], Scopus shows high flexibility in covering different subject areas and relies on many filtering tools. Following the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology [59], we carried out the literature analysis, according to four main phases:

1. Identification of relevant papers (i.e., the research area), via Scopus searching tools;
2. Screening of papers, by reading the abstract;

3. Eligibility of the papers, through the analysis of their full text;
4. Analysing information collected from the final sample of publications.

During the first phase, we identified the initial number of publications (or the research area) through the definition of:

(a) The query string, which includes some keywords, related to the objectives of the review and linked together with Boolean operators (AND/OR) within the document, the article's title or the abstract. For our purposes, we considered the following entry string, with asterisks to include derivate words too: "(citizen* AND science*) AND (gas* OR odour* OR industr*)";
(b) The type of papers. We chose peer-reviewed and original papers (i.e., articles and conference proceedings), at a final stage and written in English and, thus, significant at an international level;
(c) The time range and subject area. We specifically referred to the decade 2013–2023, thus considering the period after the creation of ECSA and the development of the modern citizen science projects. Then, we considered "environmental science" as area of interest.

No filters were selected on the authors and their affiliation, as the review was focused on evaluating the content of the research works.

Once the research area was defined, the screening of publications was performed by reading the abstract. In the end, the full text of some specific papers was assessed, after establishing n.3 quality indicators, derived from Olsen at al. [60] and reported in Table 2.

**Table 2.** Quality indicators to assess the full-text of eligible papers.

| Indicator | Description |
|---|---|
| $Q_1$ | In the study the objectives and methodology are defined |
| $Q_2$ | The study reports existing research on the topic (i.e., the context) |
| $Q_3$ | The paper discusses potential limits of the research |

The publications' analysis was performed on the final sample of documents. This phase involved first the bibliometric assessment, aimed at evaluating the bibliographic sources, the regional distribution of papers and the most relevant authors. Then, the papers' contents were organized to find out the main topics related to citizen science, as well as its advantages/limitations, for managing odour emissions in national IED plants.

Figure 1 illustrates the entire procedure to develop the literature review.

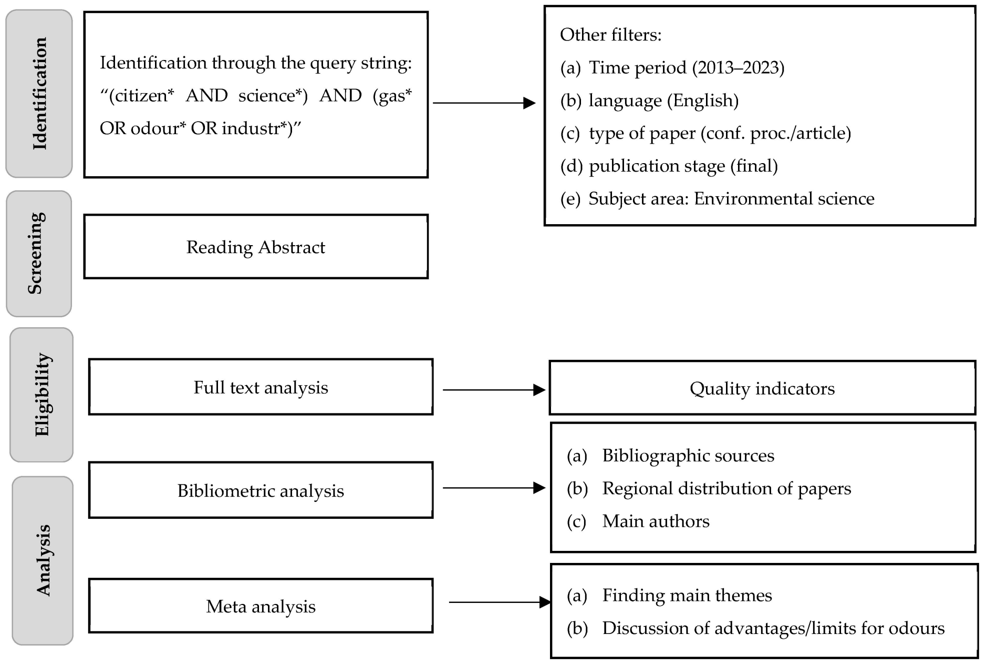



**Figure 1.** The research methodology.

## 4. Bibliometric Results

On the 4 October 2023, the literature selection process resulted in 214 publications, which were assessed in their abstract. Then, 28 papers were assessed in their full text. Finally, 14 publications were included in this systematic review. The complete list of publications is reported in Appendix A (Tables A1 and A2).

In Figure 2 the flowchart shows the number of publications included in each stage of the selection process, according to the criteria stated in the previous section.

More in detail, through the web-application Scival (developed by Elsevier [61]), 214 publications were assessed using their abstract. Then, the following information was collected from all of the papers and organized in a comma-separated values (CSV) format: Title (Column A), Authors (Column B), Year of the publication (Column C), Journal/Conference Title (Column D), DOI (Column E), Publication Type "Article/Conference Paper" (Column F), Affiliation Country of the first author (Column G) and number of citations (Column H).

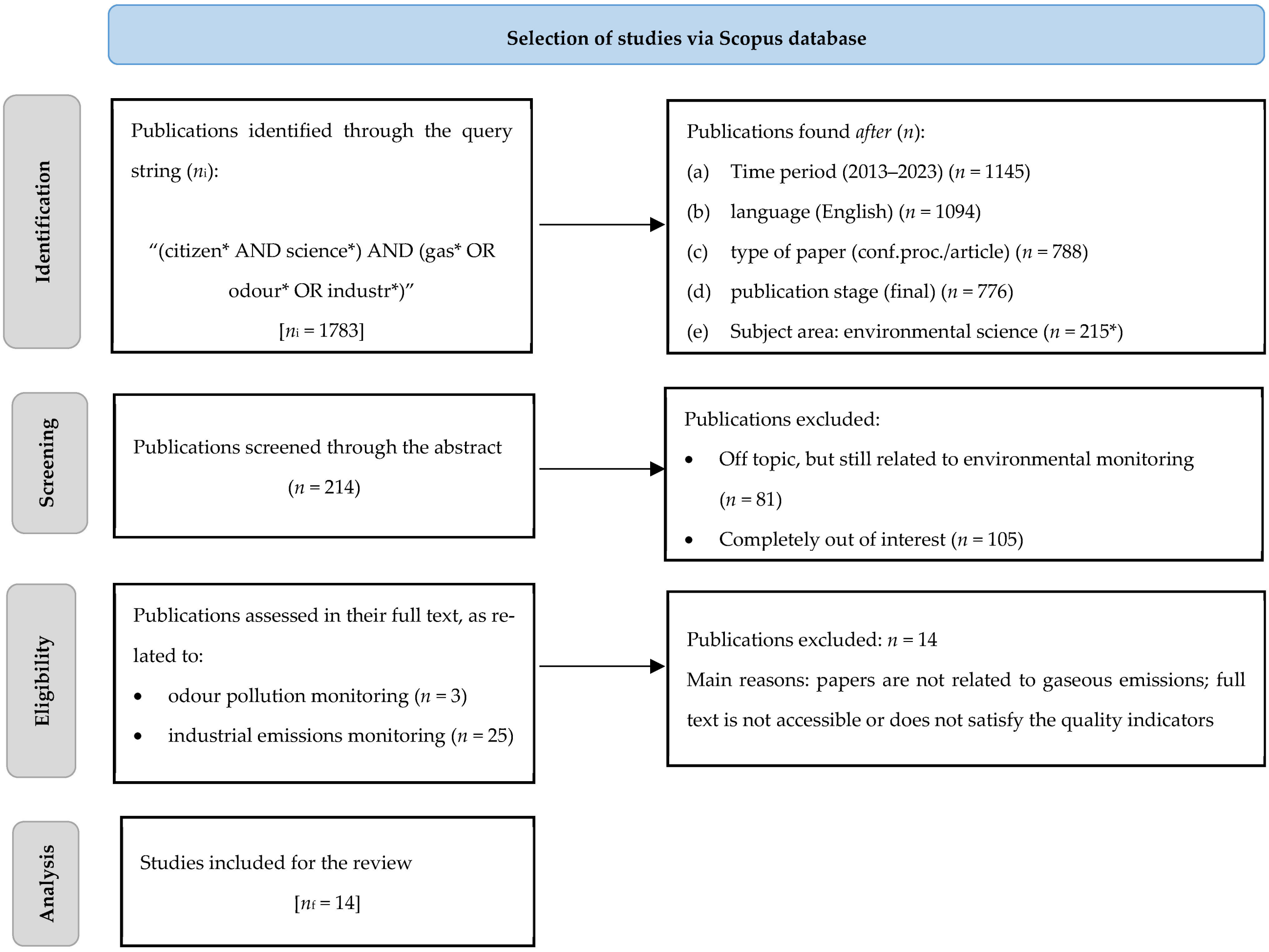
If all of the data were available, then publications were included in the review.

After that, bibliometric statistics were elaborated in a Microsoft 360 Excel environment. Bibliometrics were elaborated for the publications assessed in their full text and included in the meta-analysis (i.e., 14 articles).

As outlined by [62], bibliometrics help to understand the relevance of the topic, the most important authors in the field, as well as the regional area where the topic is most addressed. So, they can be useful to make comparisons, identify trends and suggest solutions to overcome potential gaps.

### 4.1. Bibliographic Sources

Even though we selected in the Scopus database both articles and conference proceedings, only articles were present in the final sample ($n_f$ = 14). Hence, 13 journals were considered as bibliographic sources. In Table 3, reference journals are listed in alphabetical order (only the first three refer to articles specifically focused on odour pollution management), together with their publisher and the number of related papers. The H-index is reported as an indicator of the scientific popularity of each journal [63].




*1 publication was excluded due to the lack of Scopus ID

**Figure 2.** Number of publications within the research process.

**Table 3.** List of the main bibliographic sources.

| Journal | Publisher | Country | H-Index [1] | Number of Papers |
|---|---|---|---|---|
| Detritus | CISA Publisher | Italy | 13 | 1 |
| Journal of the Air and Waste Management Association | Taylor & Francis | United Kingdom | 97 | 1 |
| Science of the Total Environment | Elsevier | Netherlands | 317 | 2 |
| Atmospheric Environment | Elsevier | United Kingdom | 270 | 1 |
| Ecological Economics | Elsevier | Netherlands | 236 | 1 |
| Environmental Practice | Taylor & Francis | United Kingdom | 29 | 1 |
| Environmental Research | Academic Press Inc. | United States | 164 | 1 |
| Environmental Research Letters | IOP Publishing Ltd. | United Kingdom | 164 | 1 |
| GeoHealth | John Wiley & Sons Inc. | United States | 24 | 1 |
| Global Environment | White Horse Press | United Kingdom | 8 | 1 |
| International Journal of Safety and Security Engineering | International Information and Engineering Technology Association | United Kingdom | 16 | 1 |
| International Journal of Environmental Research and Public Health | Multidisciplinary Digital Publishing Institute (MDPI) | Switzerland | 167 | 1 |
| Journal of Political Ecology | Bureau of Applied Research in Anthropology | United States | 31 | 1 |

[1] Reported from SCImago [64].

### 4.2. Regional Distribution of the Papers

Only three articles were found that dealt with citizen science projects to manage the odour pollution caused by industrial facilities [65–67]. Such articles were written by European scientists (from Italy, Spain, Hungary and The Netherlands).

However, we reported the regional distribution of the 14 papers, to identify the main geographical areas interested in citizen science approaches to industrial air emissions management. Hence, starting from the affiliation country of the first authors, we identified the percentages of the papers related to the main areas of the world (Europe, Asia, America and Australia).

Figure 3 reports the regional distribution of the papers. The prevalence of documents produced in America and Europe is clearly highlighted.

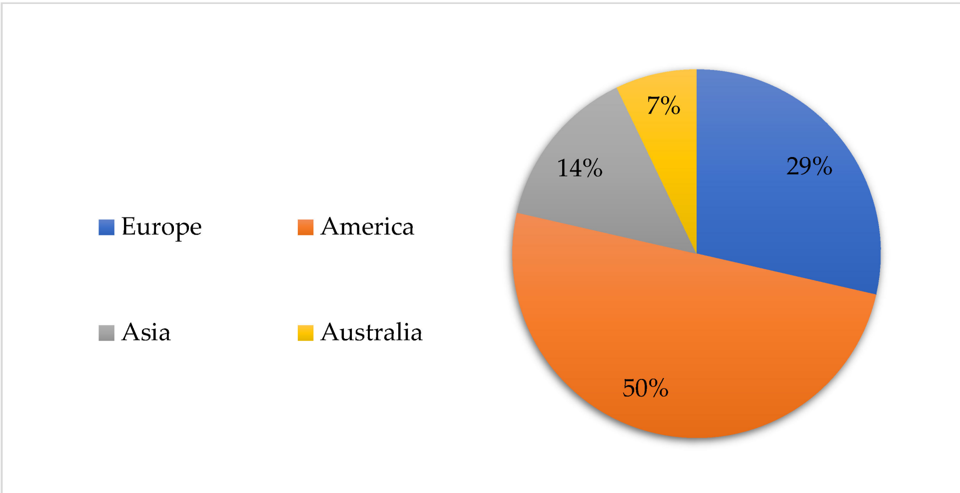



**Figure 3.** Regional distribution of the final sample (14 articles).

### 4.3. Main Authors

With reference to the final publication set, Capelli L., Di Gilio, A., Pach F.P. et al., were discovered as the main authors, dealing with participatory approaches applied to the science of odours.

However, we also provided, in Table 4, an insight on the five most cited papers and their authors, by taking into account the wider research field of citizen science applied to industrial air emissions monitoring.

**Table 4.** Top five papers according to the number of citations.

| Rank | Title | Authors | Citations | Year |
|---|---|---|---|---|
| 1 | Activism mobilising science | Conde, M. | 39 | 2014 |
| 2 | Citizen science-informed community master planning: Land use and built environment changes to increase flood resilience and decrease contaminant exposure | Newman, G. et al. | 32 | 2020 |
| 3 | WellWatch: Reflections on designing digital media for multi-sited para-ethnography | Wylie, S. et al. | 29 | 2014 |
| 4 | Reflections on a boom: Perceptions of energy development impacts in the Bakken oil patch inform environmental science & policy priorities | McGranahan, D.A. et al. | 15 | 2017 |
| 5 | Community Citizen Science for Risk Management of a Spontaneously Combusting Coal-Mine Waste Heap in Ban Chaung, Dawei District, Myanmar | Phenrat, T. | 12 | 2020 |

Results reported in the following table are listed according to the number of citations (registered in Scopus).

## 5. Main Findings

The abstract analysis (performed on the sample of 214 papers) allowed the recognition of several applications of citizen science to environmental monitoring. We summarized the main thematic fields and subtopics in Table 5.

**Table 5.** Applications of citizen science approaches to environmental monitoring (initial sample of 214 papers).

| Thematic Field [1] | Subtopics | Sub-Topic Code |
|---|---|---|
| Industrial emissions [2] | Odour pollution | ST1 |
| | Air emissions | ST2 |
| | Groundwaters | ST3 |
| | Waste | ST4 |
| | Integrated assessment [3] | ST5 |
| Air quality | Urban areas | ST6 |
| Animal biodiversity | Terrestrial fauna | ST6 |
| | Marine fauna | ST7 |
| Green spaces | Urban green areas | ST8 |
| | Wild green areas | ST9 |
| Blue spaces | Wetlands | ST10 |
| | Marine areas | ST11 |
| | Lakes | ST12 |
| | River environments | ST13 |
| Soil | Soil contamination | ST14 |
| | Waste Littering | ST15 |
| Climate change | --- | ST16 |

[1] initial sample: 214 publications; off topic, but related to environmental monitoring: 81 papers; completely out of interest: 105 papers. [2] dealing with industrial emissions monitoring: 28 papers. [3] related to several aspects of industrial impacts on environment.

Even though most of the publications were discovered to deal with citizen science applied to animal biodiversity monitoring [68,69], waste [70,71] and green and blue spaces [72–74], 14 publications were identified as related to industrial air emissions management (listed in Appendix A).

Starting from the information inside such papers, we were able to distinguish the potential advantages and limitations of the participatory approach applied to odour pollution management in national IED plants.

### 5.1. Advantages

Firstly, as outlined by [66], public engagement in odour pollution can provide further knowledge about it, through the high numbers of "sentries". Collecting several citizen complaints about odours could be an advantage to identify efficiently the potential receptors and pathways of the gas pollutants, with reference to a specific industrial installation. For instance, in the framework of the NOSE project, developed by CNR and ARPA Sicilia [75], citizen complaints helped to identify new odour hotspots in the East of Sicily, where some industrial sites of national interest are located.

Moreover, data is acquired in real time (or as soon as the odour is perceived) and can be managed remotely by operators and scientists. In fact, most of the citizen observatories/platforms for environmental monitoring are designed to be always controlled by scientists. Researchers can be also involved in the data validation and the volunteers' training [4,25,76].

Then, public engagement in odour monitoring does not require sophisticated equipment. In other words, people involved in such a monitoring programme can establish a low-cost control system. Participants are generally required to attend community activities (like interviews, paper-based surveys, site inspections, etc.) [77,78] or, in recent times, to fill in online questionnaires, accessible through ordinary devices (like smartphones, tablets, etc.) [67,79].

With reference to the questionnaire surveys, people are generally interviewed with closed questions (e.g., yes/no, 5 points Likert scale questions) and a few open questions. Hence, after a training session, the communities involved in a citizen science project are supposed to produce comparable data, which can be elaborated through statistics [80]. That could be an advantage in odour pollution management, especially for the definition of some key parameters (i.e., intensity and hedonic tone of odours, health effects).

Finally, elaborating citizen complaints about odours could be an important driver of innovation in the integrated environmental monitoring of IED plants. To illustrate this concept, we should consider that the citizen complaints rely on the use of categorical answers (e.g., a Likert-scale number, yes/no) and, in a few cases, of simple natural language. Hence, after a proper organization of the answers, they could be elaborated through data mining techniques [81]. Considering the type of data, clustering or natural language processing (NLP) techniques could be applied, as already reported in scientific literature for other purposes (e.g., the sentiment analysis of perceptions about cultural heritage [82], occupational risk assessment [83,84]).

Overall, citizen science approaches could also stimulate new data-driven policies in the framework of the IED Directive.

### *5.2. Limitations*

As outlined by [28,66], one of the main limitations could be the subjectivity inside any complaint. Subjectivity can depend on several factors, like age, sex and professional background as well as personal attitudes to negative events. So, the project of citizen science should involve as many people as possible, to reduce the influence of potential outliers and reach trustable results.

Moreover, people should be properly trained. As reported by [85,86], participants should first attend some educational sessions (or focus groups), aimed at strengthening the community capacity and their role awareness, as well as giving practical information on how to use the questionnaire/web application and provide significant feedback. The training phase could require more effort, in the case of low-skilled communities or a low number of human resources involved.

After that, it should be noticed that the public participation in odour monitoring provide operators and policy makers with qualitative results. Just to illustrate this concept, Njoku et al. [80] asked participants to rate the perception of bad odours according to the simple scheme “Serious”, “Fairly Serious”, “Not Serious” and “Did not Tell”. Hence, results derived from a citizen science approach need to be further integrated with a quantitative analysis of the odour impact.

Furthermore, in the scientific literature there has not been found evidence of a standard model to collect citizen complaints on odours [87]. Moreover, as observed by Bokowa et al. [88], odour nuisance is often summarised with the parameters related to the acronym FIDO (frequency, intensity, duration and offensiveness). However, in some countries, additional features could be added: for instance, a fifth factor, “L”, as in FIDOL, referring to the odour location [6]. Furthermore, as reported by [89], question order, length and format (open/Likert scale questions), as well as visual options, are extremely variable in social research.

Finally, other limitations can be related to the data validation and privacy protection issues. As reported by [67], data sent by non-professionals needs to be georeferenced, in order to define the odour plume evolution (both in space and time). Hence, onsite validation is essential to delete potential mistakes and false complaints. Moreover, potential issues could arise with the privacy protection of users, especially by investigating small areas through a community approach [90,91].

To sum up, Table 6 provides an overview of the pros and cons of the participatory approach applied to odour pollution monitoring for national IED plants.

**Table 6.** Advantages (√) and limitations (X) of citizen science applied to odour pollution management.

| Aspect | Advantage | Limitation |
|---|---|---|
| Identifying potential receptors and exposure pathways, as well new hotspots | √ | |
| Real-time acquisition of data | √ | |
| Low-cost monitoring of odours | √ | |
| Remote management of data | √ | |
| Production of comparable data through questionnaires | √ | |
| Use of smartphones, tablets, etc. to provide feedback | √ | |
| Automatic elaboration of citizen complaints | √ | |
| High number of people involved | √ | |
| Subjectivity inside any complaint | | X |
| Initial training for participants | | X |
| Qualitative assessment of odours | | X |
| Lack of a standard model to collect complaints | | X |
| On-site validation of data provided by participants | | X |
| Privacy protection | | X |

## 6. Discussion

Such a review was focused on research studies related to the application of participatory approaches to odour pollution management. Overall, despite the small sample of publications reviewed, the main advantages and limitations of the participatory approach in the science of odours were identified ($Q_1$ and $Q_2$ in the introduction). They were mainly related to the high number of non-professionals involved, production of further knowledge on the topic and needing the scientists' supervision to yield trustable data. Moreover, an answer to $Q_3$ (regarding the integration of citizen science in industrial odours management) was discovered in the potential use of questionnaire web-based surveys. Citizen complaints could be collected as brief reports (characterized by a stated number of closed/open answers) and further processed with data mining techniques (e.g., NLP or clustering techniques).

Overall, the low number of publications found on such a topic provided a confirmation of the great novelty of the topic. Hence, further empirical evidence is needed to better address citizen science specifically applied to odour management. Moreover, the need for objectivity (especially in the questionnaire design), as well as privacy protection issues, should be further discussed in the future.

Such results have also been considered consistent with the scientific interest in odour emissions issues, growing in popularity only in recent times and with significant difference worldwide. As reported by [88], legal frameworks on such an aspect are still under discussion in many countries. For example, in Europe there are many areas without specific regulations on odours: they are partially addressed by some guidelines. Hence, the citizens' complaints on odour emissions could be managed differently by European and international environmental protection agencies. In some cases, the great number of public complaints has promoted the revision of the integrated environmental permit released to some Italian installations. However, the lack of a model to collect the public opinion does not allow the definition of a standard to manage the citizens' complaints on such an aspect.

Looking at the bibliometric statistics, the prevalence of European scientists specifically involved in citizen science applications for odour pollution management has been considered in line with existing research projects financed on this topic [24,25]. More specifically, in Europe the integrated approach to industrial emissions has definitely promoted the scientific interest towards all industrial issues (including odour emissions). However, the high number of publications related to the American region as well is not surprising. In fact, the first citizen movements were created in the U.S.A., especially to stress the need of a participatory approach for the oil and gas industry, exploiting the hydraulic fracking of soil [78].

*Limitations of the Study*

Reducing the focus of this review to citizen science applications on odours and industrial air emissions resulted in a small final sample of publications. Moreover, such a reference sample was also due to the following:

(a) The choice of a unique reference database (Scopus), where the most significant technical articles have been indexed;
(b) The selection of the last decade (2013–2023) as the reference period. Even though some citizen science applications for environmental monitoring were discovered before 2013, we preferred to analyse those publications showing a modern concept of citizen science. So, referring to the establishment of the European Citizen Science Association, we analysed the literature published on such a topic in the last decade.

In addition, the quality criteria stated in Table 2 allowed the extraction of a low number of valuable studies. Several publications were excluded from the analysis due to the lack of a rigorous methodology, clear objectives and original experiences. To provide significant results, we tried to enlarge the publication sample with documents dealing with air industrial emissions monitoring too. However, citizen science projects in industrial areas are still not so popular worldwide and should be more encouraged.

Furthermore, in the Scopus database a lot of publications were found to focus on citizen engagement in biodiversity, waste and green/blue spaces issues. Such a result was mainly due to the automatic selection of papers through the entry query keywords and the wide use of the "citizen science" expression in most of the recent environmental studies.

Table 7 demonstrates such an aspect, providing an overview of the keywords' trend on the initial set of 214 publications, in the period 2018–2023.

Finally, the results achieved were limited by the selection of articles and conference proceedings during the phase of Identification (see Figure 1). We considered papers featuring a high degree of novelty, excluding the so-called "grey literature" (i.e., technical reports, short communications, etc.).

**Table 7.** Appearance of the main keywords in the initial set of publications (last five years).

| Keywords | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2018–2023 |
|---|---|---|---|---|---|---|---|
| Citizen science | 11 | 10 | 22 | 11 | 23 | 17 | 94 |
| Citizens | 5 | 12 | 10 | 8 | 9 | 7 | 51 |
| Science Community | 0 | 1 | 4 | 2 | 6 | 1 | 14 |
| Participatory | 0 | 0 | 2 | 0 | 3 | 1 | 6 |
| Community Based Participatory Research | 0 | 1 | 0 | 1 | 2 | 1 | 5 |

## 7. Conclusions

This study provides a systematic review of the scientific literature published in the Scopus database in the last decade (from 2013 to 2023) on citizen science applied to environmental monitoring. More specifically, the research activities were performed to identify the opportunities and limitations related to the public engagement in odour impact monitoring, inside the framework of Integrated Environmental Authorizations (IEAs). In fact, according to Directive 2010/75/UE, European industrial plants can work under the conditions stated in such permits, which should be released after balancing all of the stakeholders' interests (including citizens).

Hence, starting from some keywords entered in Scopus, we selected 14 publications out of the 214 initial papers, to discuss the public engagement in odour management in national IED plants.

The study concludes that the application of citizen science to odour impact control is still an open research field. In fact, even though participatory approaches have been promoted worldwide for environmental monitoring, in the period 2013–2023 only three studies were found out in the Scopus database with reference to such a field. Moreover, only a few were considered to deal with air industrial emissions monitoring.

Even though there was a low number of papers reviewed, gathering further knowledge from local people, using low-cost instruments and promoting automatic data elaboration were identified as some of the main advantages related to the participatory approaches applied to odour pollution management. At the same time, the need for acquiring trustable data, protecting the volunteers' privacy, on-site data validation and the lack of a standard model to collect data from citizens were recognized as open points to discuss through further research experiences.

In our opinion, this systematic review can be considered just a starting point. With the increase of research experience in such a field, the discussion of pros and cons in using participatory approaches in the science of odours could be enriched with further details. Finally, just considering the large amount of data produced by citizens, future perspectives could also rise from the investigation of the link between AI-based data elaboration and odour management.

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**Data Availability Statement:** The literature works considered for the purposes of this study are indexed in the Scopus database. Data is contained within the article, in Appendix A.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A

In Tables A1 and A2 the publications included in this review are listed.

**Table A1.** Publications focused on odour pollution management.

| Title | Document | Reference | Citations | Year |
|---|---|---|---|---|
| Community and environmental data-driven monitoring of waste management | A | [65] | 0 | 2022 |
| A sensing network involving citizens for high spatio-temporal resolution monitoring of fugitive emissions from a petroleum pre-treatment plant | A | [67] | 0 | 2021 |
| Overview of odour measurement methods: The odour observatory as an informative tool for citizen science based approaches to odour management | A | [66] | 0 | 2020 |

**Table A2.** Publications related to the industrial air emissions monitoring.

| Title | Document | Reference | Year |
|---|---|---|---|
| Activism mobilising science | A | [92] | 2014 |
| WellWatch: Reflections on designing digital media for multi-sited para-ethnography | A | [93] | 2014 |
| Show Me: Engaging Citizens in Planning for Shale Gas Development | A | [85] | 2015 |
| Reflections on a boom: Perceptions of energy development impacts in the Bakken oil patch inform environmental science & policy priorities | A | [86] | 2017 |
| The value of citizen science: The controversy over municipal solid waste incineration and dioxin pollution in contemporary China | A | [94] | 2017 |
| The importance of public participation in monitoring risks in large-scale industrial projects: An Australian experience | A | [95] | 2017 |
| Citizen science-informed community master planning: Land use and built environment changes to increase flood resilience and decrease contaminant exposure | A | [96] | 2020 |
| Community Citizen Science for Risk Management of a Spontaneously Combusting Coal-Mine Waste Heap in Ban Chaung, Dawei District, Myanmar | A | [77] | 2020 |
| Photopaper as a tool for community-level monitoring of industrially produced hydrogen sulphide and corrosion | A | [97] | 2020 |
| Community-based participatory research for low-cost air pollution monitoring in the wake of unconventional oil and gas development in the Ohio River Valley: Empowering impacted residents through community science | A | [78] | 2022 |
| Participatory environmental health research: A tool to explore the socio-exposome in a major European industrial zone | A | [76] | 2023 |

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