The Immersive Virtual Reality (VR) has the potential to significantly enhance the non-renewable energy (NRE) industry by improving safety and efficiency in operational and training processes. In order to explore applications of immersive technologies aimed at enhancing processes within the NRE energy sectors, a systematic review of the literature published in the last decade was conducted. Utilizing the PRISMA framework with snowballing, a collection of 53 articles was acquired, and subsequent examination based on indicators such as the energy industry sector, VR application use cases, and employed VR technologies (both hardware and software) revealed that only a limited number of studies (16 out of 53) met the eligibility criteria. The results revealed that in 94% of the publications, immersive VR technologies are utilized for training purposes. This research provides valuable insights and knowledge to stakeholders in the NRE industry, including companies, policymakers, and researchers, who can utilize the findings to implement immersive virtual reality technologies for complex simulations and remote operations.

Keywords: conventional energy sources, extended reality, immersive technologies, metaverse, non-renewable energy industry, virtual reality.

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Introduction

The energy sector is currently facing a complex and uncertain environment characterized by rising expenses and market instability. The recent pandemic times have led to fluctuating prices, making cost reduction essential. To tackle these difficulties, energy companies must now prioritize efficiency improvements across the entire energy lifecycle. This entails dealing with regulatory requirements, market changes, and reorienting their efforts towards improving operations and planning. The implementation of advanced technologies like VR has the potential to facilitate this optimization across all phases of the energy sector.

The energy industry refers to the sector of the economy involved in the production, refining,
distribution, and sale of energy resources. It encompasses various sources of energy, including non-renewable fossil fuels (such as coal, oil, and natural gas), renewable energy (such as solar, wind, hydroelectric, and geothermal), and nuclear energy. The energy sector also includes companies involved in energy generation, transmission and distribution, energy services, and energy trading [1], [2], [3]. This paper discusses the NRE industries, which are divided into sub-sectors as depicted in Figure 1.

By the term “Immersive technologies” authors of this publication understand VR with presence of tracking system, the movement of the person’s head is monitored and person is immersed inside the VR and has no feeling of the real world. Rather than sitting in front of the computer looking at something that is 2D on the screen and can rotate it in 3D like computer games - these are the type of applications that do not interest us as a technology and will not be included in the analysis in this systematic literature review. If there are any immersive serious games examples they will be also included. This also somewhat coincides with the definition given by Sherman & Craig (2018) [4]: “The four key elements in experiencing VR - or any reality for that matter – are a virtual world, immersion, sensory feedback (responding to user input), and interactivity”.

Several previously published literature reviews examine partially applications of immersive technologies into the NRE sector. Popov et al. (2021) [5] and Qin et al. (2020) [6] address immersive technology for training and professional development of nuclear power plant personnel. Fracaro et al. (2022) [7] conducted a comprehensive review of existing literature known as a Systematic Literature Review (SLR) to identify applications of immersive technologies that have been published in the last two decades. The main objective of this review was to identify how these technologies can enhance the training and learning experiences of operators working in the process industry, particularly within the chemical industry. To gather relevant articles, they followed the PRISMA framework and employed backward and forward snowballing techniques, resulting in a collection of 44 articles. These articles were analyzed based on several factors, including the type of training, industry context, and the specific immersive technology being used. Among the articles reviewed, only a small number (10 out of 44) included a comparison between immersive and traditional training methods. Additionally, six performance indicators were identified (time, number of mistakes, hints, instruction repetitions, events, and equipment identification) to assess the effectiveness of the immersive training experience.

Smirnova et al. (2020) [8] addresses application of immersive training technologies in the oil and gas complex. A study [9] evaluates the use of VR platforms, which is an integrated part of the digital factory for an industrial training and maintenance system. This review [10] examines the evidence for the effectiveness of VR as a medium for safety related training in mining.

The aim of this article is to create a systematic literature analysis of the application of immersive VR technologies in the field of NRE industry sectors. The first advantage of this publication and its difference from the above literature reviews is that it analyzes the literature in all sectors of the NRE industry as a whole, not only in one or a few specific sectors and the second advantage is that it covers the last decade.

![Figure 1 – Subsectors included in the NRE sector](image-url)
Method

This literature review is conducted by adapting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method [7], [11], [12]. Initially, relevant literature was identified by searching Google Scholar, Scopus, ScienceDirect, Google and ResearchGate as primary databases using keywords related to the application of VR within the energy sector and more specifically in the field of non-renewable sources. Main key phrases used: Energy industry VR, immersive technologies in energetics, haptic technologies in energy industry, virtual environments in the energy sector, collaborative VR environments.

Given the aim of this paper to identify recent trends, research gaps (if there are any) and the substantial number of existing publications in the fields, the identification and screening steps of the PRISMA method were combined into two initial steps.

The first step was to narrow down the results before further analysis of the available studies, which led to a total number of 53 papers. An extensive table was made, where the authors systematically reviewed every single paper by year, publisher, bibliographic description (in APA style), abstract, tags, keywords, use cases, sector, details regarding the main objective of the paper and types of the articles (e.g. literature review).

On the second step more precise screening was made in order to distinguish the publications meeting stricter eligible criteria: 1) Use of immersive VR, 2) NRE sources, 3) Publications after year 2012 and 4) Content in English. The authors create a new precise table including the columns: year, publisher, energy industry sector, use case – VR application, details, VR technology, hardware and software used, gaps and conclusions. At this step, the review articles are dropped, but they will be used in the section of the related works and for snowballing [13]. The snowballing technique was also used on the list of references of each source of the cited literature to find if there are missed important sources. This resulted in the discovery of eight new ones, some of them high quality, interesting and invaluable.

Second screening of all papers led to narrowing down the number to a total of 16 papers. Such as one [14] not included because written in Chinese language.

Results of the systematic literature review and discussion

In this section, the authors describe the main results of the literature review, including the year and source of the publications, brief information of the main contribution of the selected papers, broken down by energy source, as well as the main application areas of the immersive VR technology.

Figure 2 shows the lack of publications before 2015 meeting the eligible criteria described in the “Method” section. After 2015, there is a clear constant trend in the interval from 2015 to 2022 in the number of publications in internationally peer-reviewed journals, with a peak observed only in 2019.

The publications included in this analysis are published by Elsevier (N=4), MDPI, EDP Sciences, IoP, IEEE, ASP, Taylor & Francis (N=1) and other publishers (N=6) (Figure 3).
The analysis of the studies for different use cases resulted in conclusion that 94% of publications describe use of immersive VR technologies in the energy sectors with training purposes (N=15) and only in one publication such technologies were used for immersive visualizations purposes (N=1) (see Figure 4). In addition, the following detailed analysis was also conducted arranging publications by the kind of energy sources, as shown in Figure 5 (Nuclear (N=6), Oil & gas (N=4), Oil Platforms (N=2), Power / Electricity (N=2), Oil Refinery and Mining (N=1)).

The high percentage of publications dealing with simulation training forced the included papers to be analyzed additionally in details, what kind of training was used in them.
In a study [15], a group of thirteen individuals, consisting of control room personnel and field operators in a nuclear power plant (NPP), underwent training in a VR scenario. It’s important to highlight that 77% of the trainees had prior experience with VR equipment; among them, 38% had used it only once, 32% between two and five times, and 8% more than 20 times. Before the VR scenario training, 69% of the participants had a positive opinion of VR technology, while only one participant held a more reserved opinion, and none of them had a negative opinion. It’s worth noting that during the training, the participants used VR hand controllers, which did not provide mechanical resistance (no haptics were involved). These controllers allowed them to perform tasks related to mobility, rotation, teleportation, and maneuvering within the VR environment.

The VR scenario commenced in a virtual lobby, offering the participants a selection of various training tasks. Once they made their choice, they were required to select the appropriate personal protection equipment. Using a library, they accessed the correct documents and procedures and then proceeded to execute maneuvers, perform checks, and follow communication protocols. Within the VR environment, the scenario included panels, consoles, and operating stations identical to those used in the actual NPP being referenced. This allowed the trainees to engage with the sequence of operations as established in the task, operating maneuvering switches, valves, and other equipment that mirrored the components found in the real reference unit.

The article dedicated significant focus to assessing the trainees’ responses and feedback. To achieve this, they employed the Kirkpatrick framework, which aimed at evaluating two key aspects: the trainees’ acceptance of the VR training scenario tailored for the specific target group, and the trainees’ acceptance of VR technology as a viable method for conducting this type of training.

Hagita et al. (2020) [16] developed a VR implementation featuring a virtual survey meter, specifically designed for training and other applications to make VR accessible to general scientists in the field of nuclear engineering. The main objective was to showcase the effectiveness of this implementation by creating a simplified training scenario that allows beginners and non-experts to experience working in an environment with radiation sources and radiation shielding walls. Although this system is relatively basic compared to real-life operations in an actual nuclear facility, it serves as a valuable starting point for introductory training in radiation shielding. The researchers utilized steel and concrete walls as shielding materials to establish the training scenario. Within this VR environment, they created virtual survey meters, walls, and barrels using Unity native objects, and these could be manipulated by hand devices through VRTK (Virtual Reality Toolkit). To determine the accuracy of their simulation, they calculated radiation rates using a short code based on the point kernel method and verified the r−2 rule and sum rule. As part of the training scenario, they conducted exercises involving the measurement of radiation dose rate changes from three barrels while adjusting the positions of the shielding walls.

In a paper [17] present findings from their exploration of multiplayer VR applications for conducting straightforward inspection exercises. These VR applications consist of functional replicas of inspection devices, along with a two-layered radiation simulation. The first layer, termed the “simple layer,” is employed to estimate realistic count rates in Geiger and neutron counters. On the other hand, the “complex layer” adopts a hybrid approach, combining pre-computed radiation signatures and detector response functions. This hybrid approach is based on a combination of MCNP Monte Carlo simulations and deterministic methods to effectively handle shielding and attenuation effects. With the integration of these layers, the VR environment allows the manipulation of sources, detectors, and shielding materials during the inspection exercises, providing a comprehensive and interactive training platform for participants.

Nash et al. (2018) [18] presented the creation of a simulator that utilizes master-slave manipulators for dismantling a small research reactor core assembly. The paper covers the design aspects of the simulator’s hardware and the various software elements integrated into the system. The study demonstrates how this type of tool can effectively explore different options during the development of a nuclear decommissioning process. A group of 25 participants, predominantly comprising reactor center staff, took part in the study. None of the participants had prior experience with using a simulator. The results indicate that the overall acceptance was positive (above 60%) or very positive (above 80%), with an average response rate exceeding 70%. These findings suggest a favorable reception of the simulator and its potential usefulness in the context of nuclear decommissioning process development.

The VR Training Platform leverages cutting-edge VR technologies to facilitate the training of maintenance workers [19]. This platform offers the unique opportunity to practice complex work processes in advance, ensuring preparedness for unexpected situations and fostering a safe learning environment free from potential hazards. The primary goal of this platform is to reduce the
impact of human error, enhance work safety, and replace costly training centers with an innovative and secure education system featuring cost-effective periodic training sessions. One of the platform’s key features is the user’s ability to interact with the virtual environment by simply performing the “pinch” gesture to grab the nearest object. Unlike traditional appliance-based trainings, this solution eliminates the need for specialized equipment, making it more affordable and flexible since no actual machinery needs to be purchased. Despite this cost-effectiveness, the platform retains its realism and precision, surpassing conventional computer programs and videos in effectiveness. Another significant advantage of computer-supported training is the precise measurement of various parameters during exercises. For instance, maintenance working time and identifying the most challenging aspects of procedures can be accurately detected as all data are recorded and analyzed during training. Moreover, the platform allows operators to remotely assist employees, if needed, ensuring comprehensive support even from a distance. Furthermore, the system’s versatility enables it to be used anywhere, including employees’ homes, irrespective of the geographical distance from their original workplace.

The study [20] focused on exploring the potential benefits of using immersive 3D VR environments for evaluating safety-critical control room systems. The researchers compared a 3D VR control room with a traditional simulator setup, where physical panels were replaced by virtual ones. The VR control room allowed multiple operators to collaborate simultaneously and included realistic emergency procedures. The study examined technical and human factors related to using VR environments for control room tests. Two crews (six operators) participated in the evaluation, performing monitoring and operating tasks, including a simulated emergency scenario. The operators were generally successful in completing tasks and had positive feedback. They also managed the simulated loss of the main control room without significant issues. The study found that operators experienced a moderate sense of presence in the VR environment, which was slightly lower than previous studies in a different VR setup. This could be attributed to limitations of head-mounted displays, affecting immersion and control. However, simulator sickness was minimal despite extended use, indicating that it would not be a major concern for using head-mounted VR systems in control room validation tests. Operators could remove the headset during calm moments to rest. Overall, the study demonstrated the feasibility and potential advantages of using immersive 3D VR environments for evaluating safety-critical control room systems, showing successful task execution, positive operator feedback, and manageable simulator sickness.

Oil & gas sector

The primary aim of de Almeida et al. (2019) [21] is to gain insights into oil/brine/rock interfaces at the molecular level and uncover the fundamental mechanisms behind enhanced oil recovery (EOR) on an atomic scale. Through an immersive experience, users have the opportunity to interact directly with and improve their understanding of the atomic environment in the context of EOR applications. This immersive experience encompasses nano-EOR, nano-IOR, and low-salt processes at the nanoscale, involving molecular dynamics (MD) calculations of nanoparticles at oil-brine interfaces, oil-brine interactions within silica nanopores, and calcite-brine-oil interfaces.

Companies involved in Upstream Oil & Gas production are responsible for identifying, extracting, and processing raw materials. This industrial sector has experienced continuous growth while prioritizing the safety of their workforce, machinery, and overall operations [22]. To achieve these safety goals, regular training for instrumentation technicians and field operators is essential. However, the high cost of industrial equipment has necessitated the use of cost-effective tools like VR to optimize and streamline the training process.

This research proposes the creation of a virtual full immersive training system that offers a simple and safe approach to commissioning, calibrating, and mounting HART transmitters in dynamic and hazardous environments, typical of Oil & Gas process facilities. The virtual training tool has been thoroughly tested and validated by a diverse group of users, including senior and junior instrumentation technicians, senior and junior field operators, and university students.

The feedback from the users was overwhelmingly positive. Among the respondents, 70% of senior technicians, 90% of junior technicians, 50% of senior operators, and 90% of junior operators found the software to be highly useful. Additionally, 90% of university students reported that the software significantly improved their skills in commissioning industrial instrumentation.

The primary objective of Kokkinos & Mitropoulos (2022) [23] is to faithfully, efficiently, and effectively recreate near-misses, hazardous incidents, and accidents occurring in the chemical and energy industry.

The main focus of a study [24] is to investigate the reasons behind defects in Thermoelectric Generators (TEG) within the oil and gas industry. Additionally, the study aims to create a VR training platform using nano-display devices. This platform is intended for training purposes in the oil and gas sector.
industry, specifically for tasks like heat pipe removal and pipeline construction. The research identifies three contributing factors to TEG defects in the oil and gas industry: continuous exposure to heat, overproduction, and prolonged operation.

This paper [25] presents the development of a VR environment designed to immerse the emergency brigade team of an industrial unit into potential low-frequency, high-severity events. The specific case analyzed involves a scenario of a Liquefied Petroleum Gas (LPG) leakage from an oil refinery sphere. The VR game created was thoroughly tested and validated with the industrial unit’s brigade leaders, who positively received it. The results indicate that the incorporation of VR solutions has the potential to enhance the tactics and techniques employed during emergency actions in industrial units. Additionally, it can effectively support emergency brigade teams in their training, preparation, and ongoing skill development.

Training individuals to work on an oil platform involves instructing operators on the proper location and operation of numerous devices in a hazardous environment. The consequences of even a small mistake can be severe, potentially causing harm, loss of life, and compromising the integrity of the entire plant. However, access to real platforms is limited, leaving trainees to rely on photos and diagrams for learning, which fails to provide a fully immersive and realistic understanding of their job. To address these challenges, the use of realistic simulated training through VR has been successfully employed in various industries like aviation, where workers gain a better grasp of the physical environment and tasks they must perform, leading to a more comprehensive understanding of the target system. The paper [26] focuses on the techniques used to develop a simulation system for oil platform operations. By implementing various interaction techniques, the system achieves a realistic operation scenario, allowing workers to walk and operate within a virtual oil platform. Through the integration of a joystick on the wand, the user can navigate through the internal elements and experience a broad field of view, enabling them to interact with devices while remaining aware of their entire surroundings. To further enhance the realism of the simulation, recorded audio from actual machinery is spatially reproduced within the virtual environment. This combination of techniques enables a more effective and immersive training experience for oil platform operators, better preparing them for the challenges they may encounter in real-world scenarios.

Da Cruz & De Oliveira (2016) [27] introduce a Collaborative Virtual Environment (CVE) designed for offshore oil platform training. CVEs are virtual environments that allow multiple users to participate in the same simulation simultaneously. The CVE described in the paper employs a CAVE (Cave Automatic Virtual Environment) setup, which encompasses walls, a floor, and potentially a ceiling that display 3D projections, creating an immersive experience for users. The paper also discusses related works in the areas of industrial, military, and oil industry training. The application facilitates collaboration between users in both immersive CAVE setups and desktop-based environments, resulting in a highly realistic and immersive training experience. Notable training tasks covered by the application include handling gas leaks and identifying escape routes in the event of a fire. Moreover, it enables communication between the immersive user environment (CAVE setup) and a trainer interface running on a desktop setup. Through this interface, the trainer can control the user’s environment, creating training scenarios or providing assistance as needed.

Power / Electricity sectors

In the VR environment described from [28], an emergency maneuver was simulated. During this maneuver, a portion of the substation experienced a short circuit, resulting in a blackout for customers. In response, an electrician within the substation had to quickly identify the cause of the short circuit, isolate it, and attempt to restore power by interacting with the substation’s equipment.

In the article [29], the emphasis is on employing 3D modeling technology to create a virtual representation of steam turbine maintenance. By integrating VR technology and image fusion technology, the paper achieves a training program and maintenance guidance for steam turbine units. The resulting training system for VR-based steam turbine unit maintenance establishes a virtual environment where participants can conduct equipment maintenance operations during training. This approach helps lower training expenses and enhances overall training efficiency.

Mining sector

Based on accident statistics in the workplace, the mining industry ranks among the most hazardous sectors [30]. Utilizing VR technology provides an opportunity for miners, especially younger employees, to learn and practice proper behavior in a controlled and safe environment. In this paper, the authors present the results of a pilot training involving 21 individuals employed in the mining industry. Each participant underwent two simulations using different motion capture systems. The training scenario focused on blasting works, which pose significant risks in underground coal mines due
to high methane concentration levels. Deviations from the established procedures during such tasks can result in explosions, fires, and potentially lead to loss of life. The training covered various actions, including inspecting the blasting area, removing previous undetonated explosives, measuring methane concentration levels, adjusting retaining arches, washing pulverized coal, drilling blasting holes, preparing explosives, measuring stray currents, placing explosives with initiation caps in blastholes, stemming uncharged collars, connecting caps to the blasting line, checking the continuity of the blasting line, evacuating all miners from the explosion area, ensuring safety at the blasting site, detonating explosives from the proper location, and inspecting the corridor after the explosion. The evaluation of the training followed Kirkpatrick’s model, with trainees considering the system useful and experiencing positive effects even three months after the training. In most cases, high-immersion VR, combined with a wide field of view (FoV), was rated as the most effective approach for training.

The main information on the selected publications based on the energy industry sector, main use case and the immersive technologies used is summarized in Table 1.

Additionally, based on Table 1, the selected papers were analyzed according to what kind of VR immersive hardware and software technologies are implemented inside them (Figure 6 and Figure 7).

Concerning the identifiable VR hardware, various HMDs stand out as the most frequently utilized devices in the immersive VR context, accounting for 70% of the instances (N=14), followed by Oculus Rift (20%, N=4) and stationary setups like CAVE, which make up 11% of the cases (N=2).

In terms of software utilization, Unity takes the forefront with a majority share of 33% (N=6), followed by other good or lesser-known software only observed in specific individual studies.
**Table 1 – Eligible publications after screening in summary form**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sector</th>
<th>VR application / Use case</th>
<th>VR technologies used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masiello et al. (2022) [15]</td>
<td>Nuclear power sector</td>
<td>Simulation-based personnel training</td>
<td>HTC Vive with basic controllers, and they used Unity to build the scenario</td>
</tr>
<tr>
<td>Hagita et al. (2020) [16]</td>
<td>NPP</td>
<td>Training for beginners and non-experts on radiation shielding from radioactive waste containers</td>
<td>HTC Vive, Unity, and VRTK</td>
</tr>
<tr>
<td>Kütt et al. (2018) [17]</td>
<td>NPP</td>
<td>Training of plant security staff, plant operators, and other personnel</td>
<td>Unity game engine; HTC Vive Pro HMDs and tracking stations; Discord</td>
</tr>
<tr>
<td>Nash et al. (2018) [18]</td>
<td>Nuclear</td>
<td>Simulation-based training</td>
<td>HTC Vive controllers</td>
</tr>
<tr>
<td>Soós et al. (2019) [19]</td>
<td>NPP</td>
<td>Training and education for maintenance teams</td>
<td>Oculus Rift or HTC Vive headset, LEAP motion software, Stereolabs ZED (wearable computer on the back), Cyberith or Treadmill</td>
</tr>
<tr>
<td>Bergroth et al. (2018) [20]</td>
<td>NPP</td>
<td>Training of control room operators</td>
<td>Oculus Rift headset; Unity</td>
</tr>
<tr>
<td>de Almeida et al. (2019) [21]</td>
<td>Oil &amp; gas</td>
<td>Immersive visualization of oil and gas relevant systems at nanoscale</td>
<td>Two kinds of Head-mounted displays (HMDs): The first set-up consists of the HMD (HTC Vive or Oculus Rift) and their controls to navigate and interact within the VR environments with the Nomad VR and Unitymol software; For a simpler and cheaper VR visualization, they have used a VR headset device with an attached smartphone. In this case, the Nomad VR, mobile app is used.</td>
</tr>
<tr>
<td>Garcia et al. (2019) [22]</td>
<td>Oil &amp; gas</td>
<td>Technicians Training in Upstream Oil &amp; Gas production</td>
<td>Meta Quest 2 Developer kit combined with Unity Pro 3D software</td>
</tr>
<tr>
<td>Kokkinos &amp; Mitropoulos (2022) [23]</td>
<td>Oil &amp; gas</td>
<td>Training professionals</td>
<td>„The trainees use wearables for this purpose such as VR HMD, controllers, glasses and gloves”</td>
</tr>
<tr>
<td>Aziz et al. (2021) [24]</td>
<td>Oil &amp; gas</td>
<td>Training for heat pipe removal and pipeline construction with defects detection on nanoscale</td>
<td>HTC Vive, Unity 3D, Autodesk Maya software and C# Programming</td>
</tr>
<tr>
<td>Soares et al. (2019) [25]</td>
<td>Oil Refinery</td>
<td>Improve the Emergency Team Preparation</td>
<td>First person gamification; Unreal Engine 4 software</td>
</tr>
<tr>
<td>Santos et al. (2016) [26]</td>
<td>Oil Platforms</td>
<td>Simulation Training in Oil Platforms</td>
<td>CAVE; In order to reduce the costs of the projection system, it was decided to use home projectors (non-professional), leading to different strategies for stereoecopy generation. One of the formats used for stereoecopy is the side-by-side. In this format the stochastic images are formed by each eye’s images placed side-by-side. By convention, the image is positioned to the left intended for the left eye, while the right image is intended for the right eye</td>
</tr>
<tr>
<td>Da Cruz &amp; De Oliveira (2016) [27]</td>
<td>Oil Platforms</td>
<td>Training tasks</td>
<td>CAVE system for the immersive user environment and a desktop setup for the trainer interface. The CAVE system provides a high level of immersion by surrounding the user with 3D projections</td>
</tr>
<tr>
<td>Tanaka et al. (2015) [28]</td>
<td>Power / Electricity</td>
<td>Electrical substation electrician training</td>
<td>Oculus Rift and a joystick</td>
</tr>
<tr>
<td>Pan et al. (2021) [29]</td>
<td>Power plants</td>
<td>Interacting, learning and training for maintaining a steam turbine.</td>
<td>Microsoft HoloLense glasses</td>
</tr>
<tr>
<td>Grabowski &amp; Jankowski (2015) [30]</td>
<td>Mining</td>
<td>Pilot training for underground coal miners</td>
<td>Two simulations, using different motion capture systems: Razer Hydra or vision based system. HMDs with different field of view (FoV), wide (110 degrees) and relatively narrow (45 degrees).</td>
</tr>
</tbody>
</table>
Here it is worth noting the relatively high percentage use of undisclosed hardware technologies (10%) and especially undisclosed software technologies (28%). We contacted the collectives of several publications, and one collective shared in part without going into great detail, that the rest of the software (except Unity, if any plugin was used for example) is confidential and under NDA due to the sensitive nature of their work, particularly in the NPP sector.

In addition to the above, a few more things make an impression:

- the main observed gap in all the included and analyzed publications and also a field for future research and practical work is the lack of haptics in the immersive visualizations;
- two publications use the Kirkpatrick model for evaluation of the training and feedback from its participants;
- nano-level immersions are applied in two publications.

**Conclusions and future works**

The executed systematic literature review provides an overview of the applications of immersive VR in the context of NRE industry. Analyzed were 53 articles from the last 10 years, in order to show the recent uses of immersive VR.

Except for the lack of publications meeting the set eligibly criteria during the first three years of the research period, from 2015 to 2022, a consistent and evident pattern can be observed in the number of publications in internationally peer-reviewed journals. The peak of this trend was observed in 2019. The majority, 94% to be precise, of these publications discuss the utilization of immersive VR technologies in the energy sectors, primarily for training purposes. Among the 15 publications, only one focused on employing such technologies for immersive visualizations. It is worth noting that a significant portion of these publications is concentrated in the nuclear sector (6 publications) and the Oil & Gas sector (6 publications).

It was shown, that the most used application of VR is the training of personnel. The training focuses on routine tasks involving hazardous and expensive equipment, working with radiation sources and shielding walls, equipment inspection, and dismantling small research reactors. Additionally, the training covers commissioning, calibrating, and mounting equipment in dynamic and hazardous environments, simulating near-misses, incidents, and accidents in the chemical and energy industry. It also includes inspection at the nano scale, handling leakage from an oil refinery sphere, emergency maneuvers for short circuits, steam turbine maintenance, and practicing safe behavior in a controlled environment.

The most commonly used hardware are various HMDs, accounting for 70% of cases, followed by Oculus Rift (20%) and like CAVE, which make up 10% of instances. Regarding software, Unity is the predominant choice with a majority share of 33%, while other good or lesser-known software is observed in specific individual studies.

It is worth noting a relatively high percentage of undisclosed hardware (10%) and undisclosed software (28%). The opinion of the authors of this publication is that the reason for this is the use of confidential software and plugins under a non-disclosure agreement due to the sensitive nature of the investigated sectors.

As a next step and subject of future follow-up research could consider studying the same question over the same period regarding renewable energy sectors and comparing it to non-renewable.

It can be concluded that until 2015 the energy and utilities sectors can be considered slow in adopting the new VR technologies.

This research shows that more and more companies starting to apply VR and the immersive VR technologies in the NRE sector are a source for 1) significant saving of financial resources needed for expensive and dangerous NRE equipment and 2) not least preserving the health and life of workers by preparing and training them in a safe environment.

Immersive virtual reality can significantly enhance nuclear safety in nuclear power plants. By providing realistic lifelike training environments, accurate plant simulations and improved human performance under stress, immersive virtual reality can significantly improve the preparedness and response of NPP personnel to various operational challenges and emergency scenarios. This technology offers reduced risks and costs associated with physical training, promotes a culture of safety, and enables remote collaboration for safer decision-making. Ultimately, immersive VR improves preparedness, refines protocols, and reduces risks in nuclear operations, ensuring safer facilities and more effective emergency responses.

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**Conflict of interest**

The authors have no conflict of interest to declare.
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З метою дослідження застосувань імерсивних технологій, спрямованих на покращення процесів у сферах невідновлювальної енергетики, був проведений систематичний огляд літератури, опублікованої за останнє десятиліття. За допомогою фреймворк PRISMA із застосуванням методу «снігової кулі» було зібрано колекцію з 53 статей; і подальший їх аналіз за такими показниками, як сектор енергетики, використання VR-додатків, а також застосовані VR-технології (як апаратне, так і програмне забезпечення), показав, що лише обмежена кількість досліджень (16 з 53) відповідали вимогам до відбору. Результати показали, що у 94 % публікацій імерсивні VR-технології використовуються для навчальних цілей. Це дослідження надає цінні розуміння та знання зацікавленим сторонам у галузі невідновлюваної енергетики, включаючи компанії, політики та дослідників, які можуть використовувати знайдені результати для впровадження імерсивних VR-технологій для складних симуляцій та віддалених операцій.

Ключові слова: віртуальна реальність, галузь невідновлюваної енергетики, імерсивні технології, метавсесвіт, розширена реальність, традиційні джерела енергії.

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