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# Industrial Fire Safety in Türkiye: A Retrospective Analysis of Fire-Related Occupational Accidents (2012–2022)

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## Highlights

- Fire-related accidents accounted for 5.3% of all workplace accidents and 11.6% of fatalities.
- Gender-based analyses revealed that male workers were affected at a higher rate ($p$<0.001).
- Fatal fire accidents reveal ongoing structural risks in workplaces.
- A multi-layered fire safety model integrating data, technology, and policy was proposed.

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## Abstract

Fire incidents continue to pose a significant public safety and occupational health risk worldwide. According to the International Technical Committee on Fire Prevention and Firefighting (2023), fire-related death rates range from 3 to 5 per 100,000 people in developed countries such as the United States, Germany, and Japan, while in developing countries such as India, Pakistan, and Nigeria, these rates can reach 25 to 45 per 100,000 people. In Türkiye, the fire-related death rate was approximately 7 per 100,000 people in 2022, placing the country in the middle-income group. The absence of a centralized and standardized national fire incident database in Türkiye limits the comprehensive analysis of fire-related workplace accidents. Therefore, this study examines the distribution and characteristics of fire-related workplace accidents using Social Security Institution (SSI) data covering the 2012–2022 period. Statistical analyses were conducted using Pearson's chi-square and Fisher–Freeman–Halton tests. The findings indicate that fire-related accidents account for approximately 5.3% of all workplace accidents and 11.6% of fatal cases. According to SSI records, these accidents are predominantly concentrated in categories C1 (≈42%) and C2 (≈39%). A gender-based analysis indicates that male workers are significantly more affected by fire-related workplace accidents ($p$<0.001). These findings should be considered as preliminary evidence derived from existing official data. The results highlight the strategic importance of establishing a transparent, centralized, and internationally compliant national fire data monitoring system in Turkiye. Such an approach would also contribute to the achievement of United Nations Sustainable Development Goals (SDGs) 8 and 9.

## 1. INTRODUCTION

The discovery of fire is a revolution in the history of civilization. The ability to control fire enabled humans to meet a variety of needs. Being able to use it for purposes such as cooking, heating, and lighting is one of the greatest advances in human history [1]. Combustion is an exothermic reaction in which a combustible material combines with oxygen and a heat source in specific proportions to release heat and light energy [2]. Although fire is an integral part of nature, human activities have significantly increased its frequency and destructive power [3]. The development of technology and industry has increased the use of chemical, electrical and hot work equipment in industrial facilities; this situation paves the way for industrial fires and explosions if precautions are not taken. Such accidents, or fires known as uncontrolled combustion, can affect not only the site of the incident but also the surrounding area due to leaking toxic and suffocating gases, leading to chronic diseases in humans and environmental pollution in the long term [4-6]. One of the most well-known examples of this is the 'dioxin' gas released into the environment following a reactor

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explosion in the Italian town of Seveso on 10 July 1976. This incident caused health problems such as animal and human deaths, skin burns and cancer, and led to the European Commission issuing the 'Seveso Directives' [7].

To assess the global impact of uncontrolled burning, organisations such as the International Association of Fire and Rescue Services (IAFRS) and the World Health Organisation (WHO) regularly publish fire statistics. According to the 2019 report by the International Association of Fire and Rescue Services Centre for Fire Statistics (CTIF), among the countries with more than 300 fire-related deaths per year, India (45,197), China (10,356) and Nigeria (8,950) ranked highest, while Türkiye (695) ranked 60th [8]. When the 2022 data is examined, converted based on the 2019 annual threshold of 300 deaths, a decline of over 20% is observed in both India and Türkiye. As can be seen in Figure 1, such statistical data is critical for accurately understanding fire risks and effectively allocating national firefighting resources. The most dramatic increase occurred in South Africa, at 147.6 per cent [9].

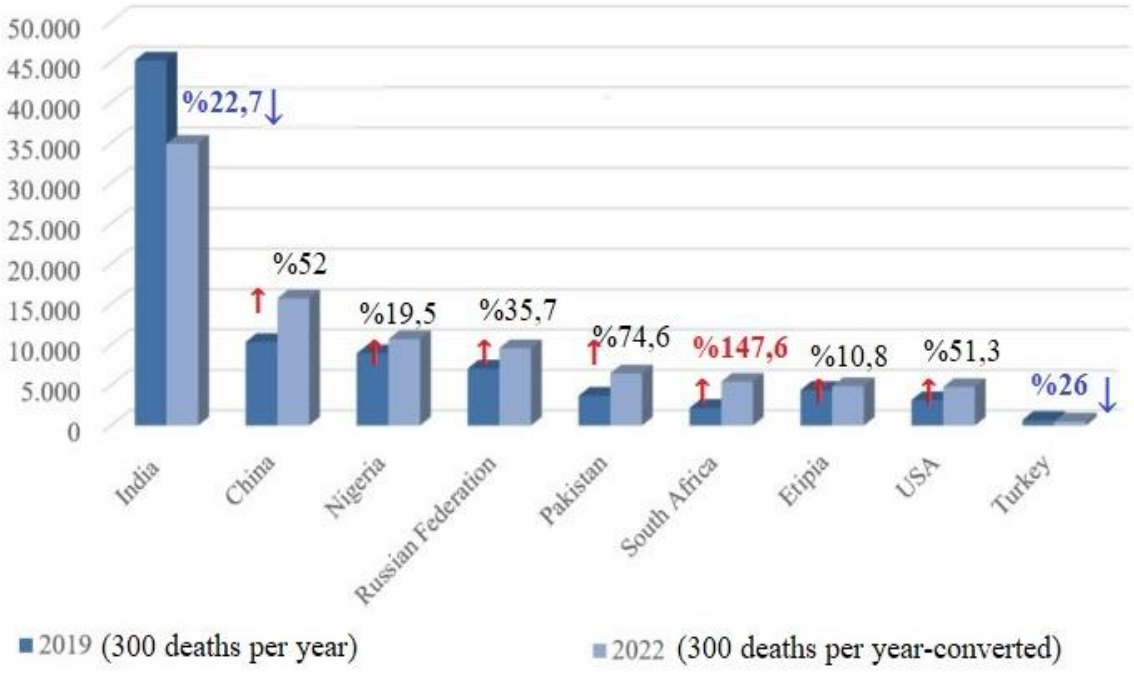



***Figure 1.*** *Percentage change in deaths per year statistics according to CTIF data*

Another piece of data used in evaluating fire statistics is the number of fire calls. According to 2023 CTIF data, Hong Kong (810,218) ranked first, Paris (495,397) second, and Istanbul (122,544) sixth in the number of fire calls in cities worldwide between 2017 and 2021. A 6.7% increase in calls was observed in Istanbul between 2019 and 2023, reflecting the high call volume in large metropolitan areas and the extensive response areas assigned to fire stations; Istanbul controls an average area of 42.7 km² [8].

According to the 2018 report by the National Fire Protection Association (NFPA), a civil society organisation that collects fire and disaster statistics in the USA, industrial fires caused an average of $1.2 billion in property damage per year between 2011 and 2015. Industrial fires occur less frequently than residential fires but result in more heat and widespread material damage [10]. Another well-known civil society organisation is the Emergency Events Database (EMDAT), maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain in Belgium. Since 1988, it has recorded more than 26,000 events related to technological and natural disasters. Criteria for an event to be recorded as a disaster include at least 10 deaths or 100 injuries, a declaration of emergency, and a call for international aid [11,12]. The largest event in Türkiye meeting these criteria was the mining disaster in Soma, Manisa, on 13 May 2014, in which 301 people lost their lives [13,14].

In Türkiye, some civil society organizations share industrial accident statistics as unofficial data instead of official institutions. One of these reports was published by the Chamber of Chemical Engineers for the

years 2021 and 2022. Therefore, the findings are presented not as definitive and generalizable statistics, but rather to highlight the current data gap and fragmented reporting structure in Türkiye. The 2022 industrial fires report and a study published in 2021 report that the majority of fires and explosions (73%) are concentrated in relatively high-risk sectors such as metal, textiles, wood, paper, furniture, rubber, and plastics. In terms of geographical distribution, 50.6% of cases occurred in the Marmara Region, mainly in Istanbul, and 28.8% were reported in the Aegean Region. Although the rate of factory fires in Istanbul and other large cities appears relatively low, it is 2.8% for Istanbul [15, 16].

Figure 2 systematically summarizes the current legislation on fire safety, the main causes of industrial fires, and the effects of fire-related injuries. The aim is to define the main headings and related structures, which will be explained in detail in the introduction.

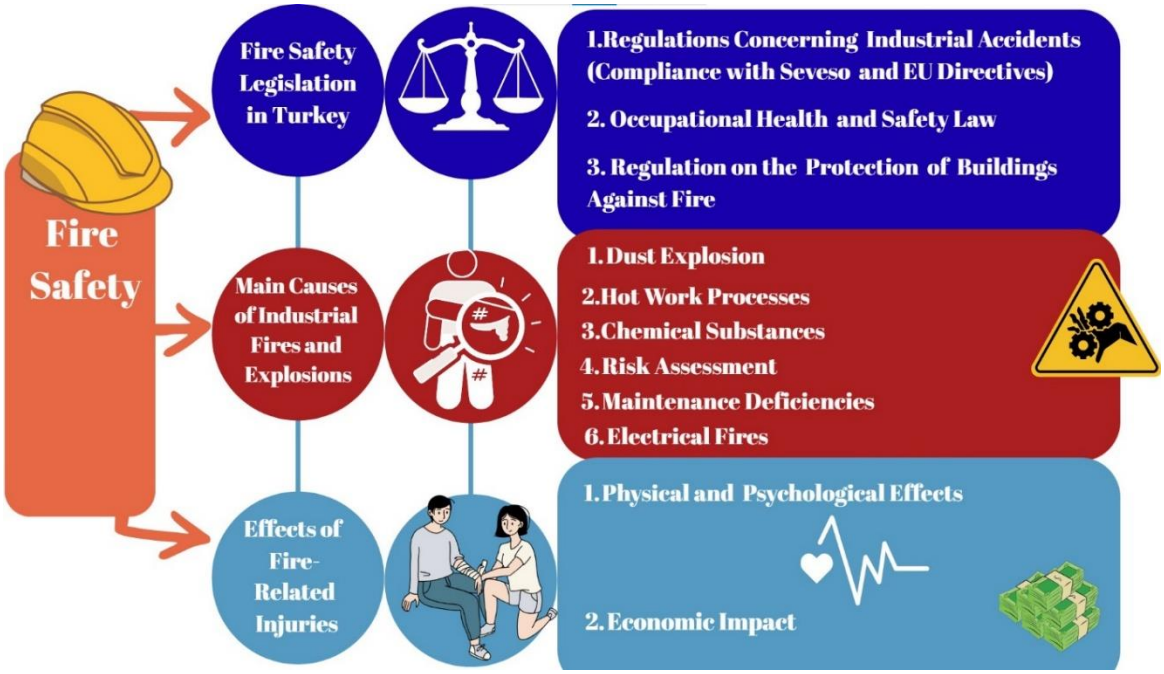



***Figure 2.*** *Fire safety*

### 1.1. Fire Safety Legislation in Türkiye

Türkiye has developed legislation compliant with the European Union (EU) Seveso Directives 2000 and 2012, which aim to prevent major industrial accidents [17]. An important part of these directives is the European Commission Major Accident Reporting System (eMARS), where accidents and near misses are reported. eMARS data shows that the main sectors with the highest concentration of accidents are general chemical production (approximately 32%) and petrochemicals/refining (approximately 24%). Such accidents associated with substantial economic losses [18,19].

With the law numbered 6331, which came into force in 2012, occupational health and safety was brought together under a single umbrella. The regulations issued under this law impose certain legal obligations on employers to both prevent and mitigate the effects of major industrial accidents, and to prevent and eliminate risks [20]. In this context, the Regulation on the Prevention and Mitigation of the Effects of Major Industrial Accidents (BEKRA) came into force in 2019, strengthening the system. The arrangement of accident prevention measures according to the risk level of the facilities is implemented as a legal obligation [21]. On the other hand, the Regulation on the Classification, Labelling and Packaging of Chemical Substances and Mixtures guarantees standard classification and labelling of chemicals according to their physical hazards [22, 23]. In workplaces with explosive atmosphere risks, reducing worker exposure, managing explosion risks, ensuring equipment suitability, and marking hazard zones are among the employer's legal responsibilities under the ATEX Regulations (ATEX 137/99/92/EC and ATEX 100a/2014/34/EU compliant) [24-27].

In addition, regulations such as workplace opening permits and the Environmental Law also contribute indirectly to fire safety processes and support the establishment of a comprehensive risk management culture [28, 29]. The first comprehensive legal regulation in the field of fire safety in Türkiye was the 'Istanbul Municipality Fire Prevention Regulation' published in 1992. However, the fact that this regulation was only applied at the local level and that standard differences emerged created a need for comprehensive legislation at the national level. To address this shortcoming, the 'Regulation on Fire Protection in Buildings' (BYKHY) came into force in 2007. BYKHY aims to protect life and property, set national standards for fire prevention, and define effective intervention processes in the event of a fire [30].

### 1.2. Main Causes of Industrial Fires and Explosions

To ensure fire safety in industrial facilities, measures such as controlling combustible dust, implementing hot work procedures, managing chemical usage, maintaining equipment, and conducting electrical inspections must be integrated into the system. In sectors such as metal and food processing, secondary dust explosions, which are much more destructive than the primary explosion, can be prevented by incorporating regular cleaning procedures and engineering solutions into the process [31, 32]. Solutions such as adapting "Work Permit Procedures" to the system [33-35] for hot work such as welding and cutting, and storing chemicals in accordance with MSDS forms, are effective in prevention. In addition to all these, control can be achieved with mathematical models that prevent the domino effect associated with chain reactions in the event of possible chemical spills [36-40]. Periodic maintenance of mechanical friction, insufficient lubrication, and overheated equipment is another factor [41, 42]. Furthermore, eliminating faulty electrical installations, loose connections, and grounding deficiencies is often used to eliminate the risk of fire at its source [43-48].

Fire safety literature is generally represented in three main categories: residential, forest, and industrial fires. Industrial fires, in turn, are based on numerous sub-areas such as explosions, electrical accidents, and structural fires. The classification of the Social Security Institution (SSI) has been used as a basis for this study. Particular focus has been placed on fire and burn-related occupational accidents in industrial processes. Figure 3, schematically illustrates the place of industrial accidents within the hierarchy of fire types.

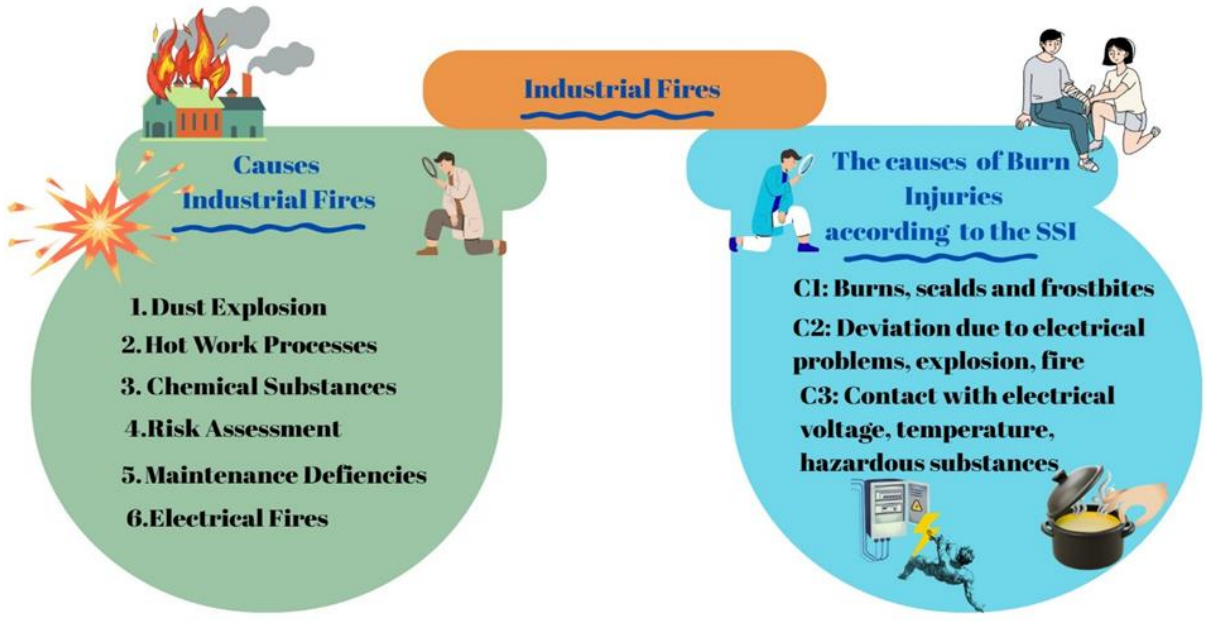



***Figure 3.*** *Causes of fire industrial burn injury categories according to SSI*

### 1.3. Effects of Fire-Related Injuries

Industrial fires not only cause physical destruction but also lead to long treatment processes requiring hospitalization. According to the literature, it is a serious public health problem, accounting for 29% of burn cases [49,50]. There are publications indicating that the recovery process after injury is directly affected by factors such as age, gender, and comorbidities. It is also reported that up to 65% of accident victims experience psychological effects such as Post-Traumatic Stress Disorder (PTSD) and anxiety [51-53]. In recent years, incentives have been provided to businesses in the Turkish economy to mitigate these risks by relocating industrial facilities outside city limits. In this way, specialized Organized Industrial Zones (OIZ) are being created from the outset [54]. An integrated structure is being established, ranging from transportation to natural disaster plans. One of these is the prevention of industrial fires. According to the NFPA, an industrial fire breaks out every 7 minutes worldwide. Fires exert pressure on the country's economy with their environmental, human, and economic dimensions. In this sense, Türkiye is among the countries with the potential to suffer serious economic damage from fires. Although not officially published, indirect studies indicate that the total annual cost of industrial fires to the country's economy reaches 19 billion ₺. Despite this, it has been reported that only 40% of facilities are insured [15, 55]. This information has been used to initiate discussion on the extent to which businesses are economically vulnerable and should not be interpreted as definitive and verified official data.

The contribution of this study is twofold: (i) to provide an exploratory basis based on existing official data, and (ii) to demonstrate the need for a centralized and standardized fire database in Türkiye. Therefore, the findings should be evaluated in favor of indicative results that reveal existing data gaps, rather than as definitive national statistics.

RQ1: What is the institutional structure of data collection, classification, and reporting systems related to fire incidents in Türkiye, and to what extent do these systems comply with international data standards?

RQ2: What is the proportion of industrial accidents related to burns among the total number of workplace accidents reported in Türkiye between 2012 and 2022, and how has this proportion trended over the years?

RQ3: Is there a statistically significant difference in the frequency of occurrence between the variables of year and gender in fire-related occupational accidents between 2012 and 2022?

## 2. MATERIAL METHOD

During the study, the data systems of the Turkish Statistical Institute (TÜİK) and the Disaster and Emergency Management Presidency (AFAD) were examined. However, there is no central national and epidemiological database on fire incidents and an integrated dataset on industrial fires in Türkiye. Therefore, the analyses were limited to the SSI open-source reports for the years 2012–2022, accessed on April 25, 2024. This research should be interpreted as a descriptive, exploratory, and retrospective study. The causes of workplace accidents resulting in burns, their categorical distributions, and the associated numbers of injuries and deaths were examined. Due to data gaps, certain indicators and subcategories were inaccessible. This situation has been documented in existing studies and noted as a significant methodological limitation for data users. In the second phase, the relationships between causes and variations by gender and year were exploratorily analyzed using Pearson’s chi-square and Fisher–Freeman–Halton tests.

The variables included year, gender, and type of accident. Pearson Chi-Square is a standard method used to test for distribution similarities and frequency deviations between groups. This test is used if the expected values in the cells are greater than 5. As for the Fisher-Freeman-Halton test, the Pearson test may yield unreliable results due to low frequencies in rare accident types or small subgroups in some categories of the data set. This non-parametric test was used in tables larger than 2x2 to prevent errors arising from sample size and to maintain statistical accuracy.

According to SSI annual reports cover death and temporary incapacity in three categorical variables and has been processed as a separate Microsoft Excel file for each year [56]. Burn-related occupational accidents were classified under three main categories. Burns, scalds and frostbites (C1), Deviation due to electrical problems, explosion, fire (C2), and Contact with electrical voltage, temperature, hazardous substances (C3). Statistical analysis of the data was performed using IBM SPSS v.27 (SPSS Inc., USA). Descriptive statistics are expressed as numbers (n) and percentages (%). Filtering operations were performed on the data set to first access the total incapacity periods and fatal accident statistics, followed by an analysis of the distribution of fire-related accidents by year and gender-based differences. Differences between the gender and year variables were evaluated using Pearson's Chi-Square and Fisher–Freeman–Halton tests. Statistical significance was set at $p < 0.05$. The findings are supported by tables and graphs.

## 3. VISUAL DESCRIPTION OF WORK-RELATED ACCIDENTS CAUSED BY BURNS

This section visually presents the overall distribution and temporal trends of occupational accidents caused by fire, thereby answering research question RQ2.In this section, fatal and injury-causing work accidents are addressed in two main groups; within each group, three main accident cause subcategories are evaluated: “burns, scalds, and frostbites (C1)”, “deviation due to electrical problems, explosion, fire (C2)”, and “contact with electrical voltage, temperature, hazardous substances (C3)”. The relationships between the distribution of disability duration and fatal accident numbers for these subcategories, broken down by gender and year, were analyzed using Pearson's Chi-Square and Fisher–Freeman–Halton tests.

In this study, the rates of burn-related accidents within the total number of accidents between 2012 and 2022 were calculated using SSI data and are shown in Figure 4. In 2012, they accounted for 2.2% of total work accidents based on the duration of incapacity to work, reaching the highest level of 6.21% in 2015. There are fluctuations over the years. The graph reflects both numerical and proportional changes over the years.




***Figure 4.*** *Number of fire-related workplace accidents among total workplace accidents by duration of incapacity (2012–2022)*

The total number of insured persons who suffered work-related accidents was 422,463 in 2019, decreased by 9.05% in 2020, but showed a significant increase of 33.01% in 2021. Despite this overall fluctuation,

the proportion of fire-related accidents within the total number of accidents remained at similar levels in 2020 and 2021 compared to previous periods. Despite the widespread adoption of remote work during the pandemic, there has been no change in the rate of fire-related workplace accidents. This indicates that fire-related risks persist independently of pandemic conditions. Fire hazards must be assessed and controlled separately and continuously as part of occupational safety management.

Total fatalities resulting from workplace accidents and their annual changes were analyzed for the period 2012–2022. The number and rate of fatalities resulting from burn-related accidents were calculated and are presented in Figure 5. Since no data was available for the C1, C2, and C3 categories for 2012, this year is shown as "N/A" (not available). The graph reflects both numerical and proportional changes over the years.

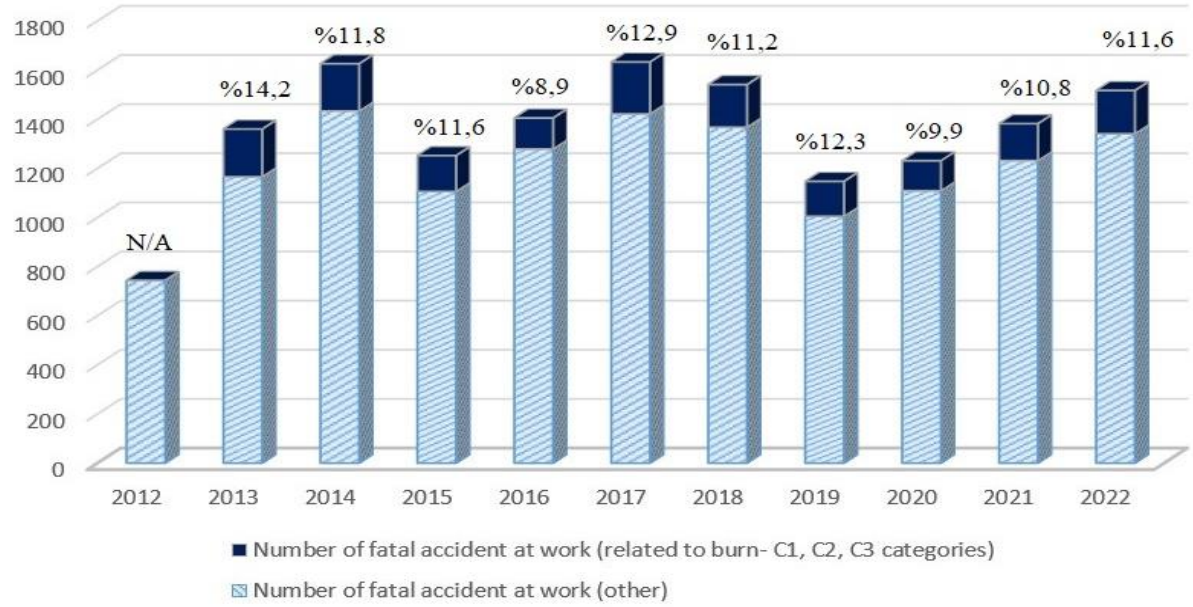



***Figure 5.*** *Annual distribution of fire-related deaths among total work-related accidents in Türkiye (2012–2022)*

In 2013, the share of deaths resulting from burn-related occupational accidents among total work-related deaths reached its highest level at 14.2%, while in 2017 this rate declined to 12.9%, the second highest level.

## 4. STATISTICAL ANALYSIS OF BURN-RELATED WORK ACCIDENTS

This section aims to explain the answer to the research question RQ1. The analysis reveals that the collection of fire data in Türkiye takes place within a fragmented and decentralized structure managed by municipal fire departments.It has been observed that this data is transmitted to national-level institutions such as AFAD only in the form of summary statistics [7, 17]. Furthermore, a lack of standardization in the flow of data between institutions is evident. Furthermore, there is no full alignment with internationally recognized standards such as the International Classification for Fire Statistics (CTIF) regarding the coding of fire causes [8]. This situation has led to variations in the terminology and classification criteria used in reports from different agencies. Additionally, detailed risk analysis variables such as building type and ignition source are not statistically included in these reports. As a result, the current system demonstrates only limited compliance with international reporting standards in terms of data standardization and classification categories [28-30, 55].

In the second stage, the relationships between fire-related occupational accidents obtained from SSI data and gender, year, and accident categories will be statistically analyzed and evaluated within the scope of RQ3. In this subsection, burn-related occupational accidents were analyzed based on work disability

duration. Findings were evaluated based on the distribution between the gender variable and the C1, C2, and C3 categories and years. The annual distribution and change rates are presented in Figure 6.

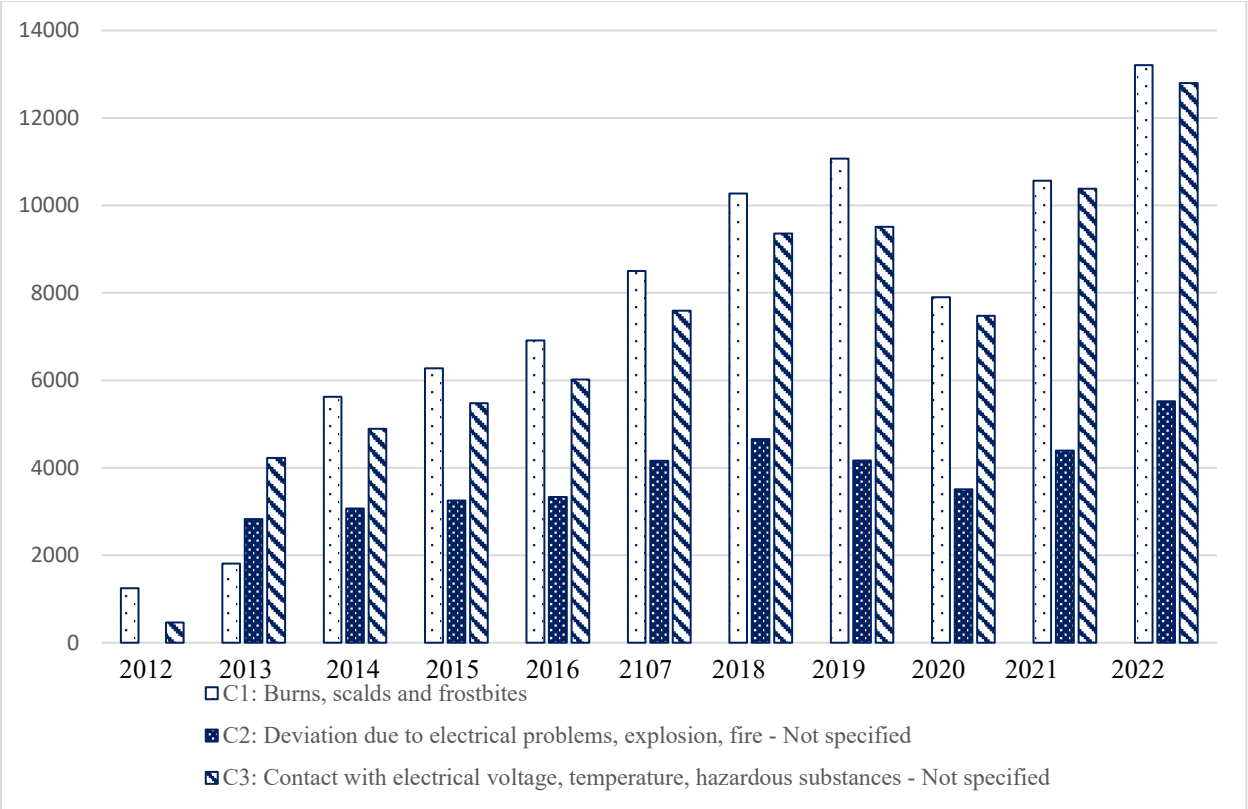



***Figure 6.*** *Change in work incapacity periods related to fire injuries by year (2012-2022)*

Category C1 has the highest incidence rate and reached its peak in 2022. Category C3 has a lower incidence rate than C1 but has shown a similar upward trend over the years. Category C2 has a more balanced distribution, with annual change rates showing less fluctuation compared to the other two categories.

The annual changes in these three work accident categories, based on burn-related disability periods examined in SSI annual reports, are presented in Table 1 according to the gender variable. The data obtained were statistically evaluated using Pearson Chi-Square and Fisher–Freeman–Halton tests.

***Table 1.*** *Annual distribution of fire-related incapacity periods by gender (2012–2022)*

| Workers by Incapacity Days | | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | $\chi 2$, $p$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | M | n | 1138 | 1798 | 4570 | 5008 | 5396 | 6502 | 7553 | 7814 | 5974 | 7826 | 9096 | $\chi 2$=1395.96, $p$<0.001 |
| | | % | 91.3 | 99.5 | 81.2 | 79.8 | 78.0 | 76.5 | 73.5 | 70.6 | 75.6 | 74.1 | 68.9 | |
| | F | n | 108 | 9 | 1056 | 1269 | 1519 | 2000 | 2718 | 3258 | 1925 | 2740 | 4111 | |
| | | % | 8.7 | 0.5 | 18.8 | 20.2 | 22.0 | 23.5 | 26.5 | 29.4 | 24.4 | 25.9 | 31.1 | |
| C2 | M | n | 0 | 2667 | 2852 | 3007 | 3070 | 3829 | 4180 | 3703 | 3182 | 3965 | 4753 | $\chi 2$=248.751, $p$<0.001 |
| | | % | 0.0 | 94.4 | 92.9 | 92.5 | 92.2 | 92.0 | 89.8 | 88.8 | 90.7 | 90.2 | 86.1 | |
| | F | n | 0 | 159 | 218 | 245 | 260 | 332 | 474 | 467 | 327 | 431 | 767 | |
| | | % | 0.0 | 5.6 | 7.1 | 7.5 | 7.8 | 8.0 | 10.2 | 11.2 | 9.3 | 9.8 | 13.9 | |
| C3 | M | n | 438 | 3793 | 4313 | 4715 | 5141 | 6363 | 7739 | 7529 | 6335 | 8585 | 10144 | $\chi 2$=591.994, $p$<0.001 |
| | | % | 95.4 | 89.8 | 88.2 | 86.1 | 85.4 | 83.8 | 82.7 | 79.2 | 84.7 | 82.7 | 79.3 | |
| | F | n | 21 | 431 | 578 | 762 | 878 | 1227 | 1621 | 1979 | 1143 | 1799 | 2653 | |
| | | % | 4.6 | 10.2 | 11.8 | 13.9 | 14.6 | 16.2 | 17.3 | 20.8 | 15.3 | 17.3 | 20.7 | |

*C1: Burns, scalds and frostbites;C2: Deviation due to electrical problems, explosion, fire;C3: Contact with electrical voltage, temperature, hazardous substances (M:Male, F: Female)*

The analysis results indicated statistically significant associations within the available dataset ($p < 0.001$). Table 1 clearly shows that male workers are more exposed to fire-related occupational accidents. However, recent data indicate that the rate of fire-related occupational accidents among female workers is increasing ($\chi^2$ test: $p < 0.001$ in all categories). This gender disparity can be attributed, in part, to structural features of the labor market, such as the higher concentration of male workers in high-risk industrial sectors where fire-related hazards are more common, including heavy industry, metal production, and petrochemical plants. Given the limitations of the primary data sources, these findings should be interpreted for research purposes and as indicative only.

This subsection analyzes fatal burn-related occupational accidents by gender, accident category (C1-C3), and year. The relationships between variables were examined using Pearson Chi-Square and Fisher-Freeman-Halton tests. Figure 7 clearly shows that the C2 category was the most prominent cause of death among workers who lost their lives as a result of fire-related occupational accidents throughout all years. Burns following a fire appear to be frequently associated with fire-related deaths.

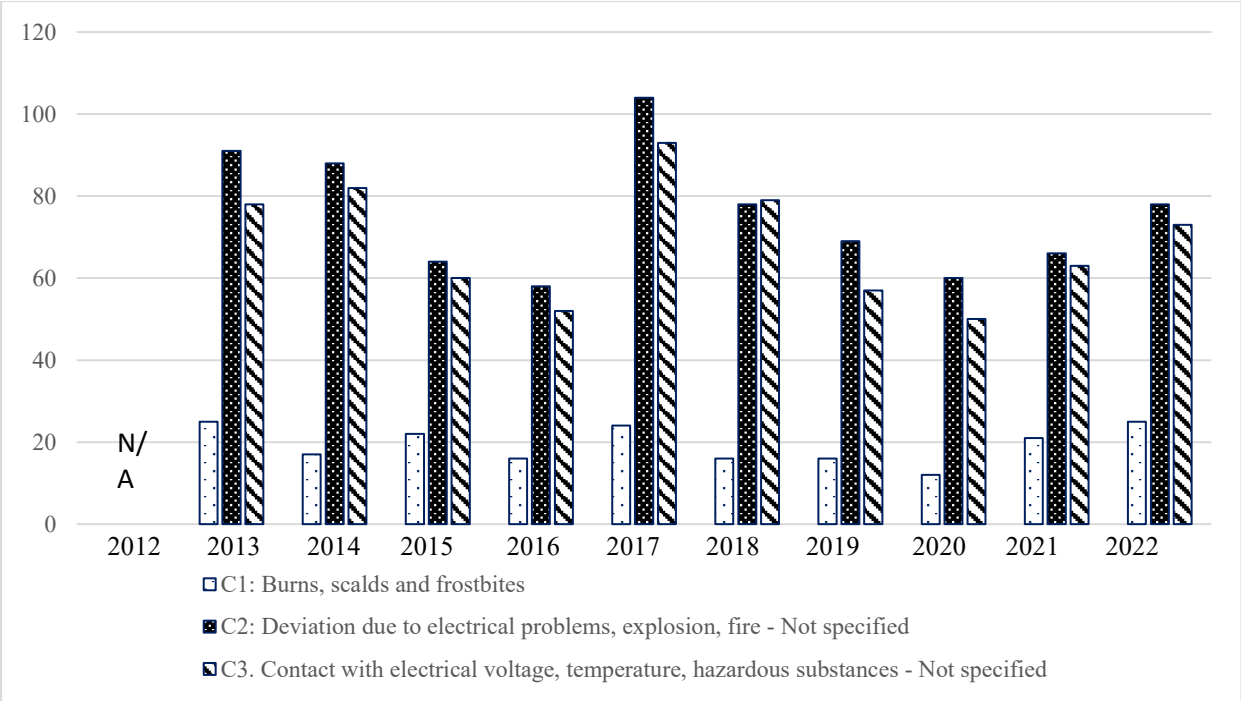



***Figure 7.*** *Distribution of fatal work accidents related to fire by year (2012-2022)*

Table 2 shows the distribution of fatal workplace accidents caused by fires over the years. According to this table, there has been no significant decrease in the number of fatal fire-related accidents over the years. In fact, there has been an upward trend in some years. This finding indicates shortcomings in the effectiveness and sustainability of fire prevention culture, risk awareness, and emergency management practices in industrial facilities.

***Table 2.*** *Annual distribution of fire-related fatal occupational accidents by gender (2012–2022)*

| Fatal accidents | | | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | $\chi 2$, $p$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | M | n | 0 | 25 | 17 | 22 | 16 | 24 | 15 | 15 | 12 | 21 | 24 | $\chi 2$=13.715, $p$=0.005 |
| | | % | 0.0 | 100.0 | 77.3 | 100.0 | 100.0 | 100.0 | 93.7 | 93.7 | 100.0 | 100.0 | 0.96 | |
| | F | n | 0 | 0 | 5 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | |
| | | % | 0.0 | 0.0 | 22.7 | 0.0 | 0.0 | 0.0 | 6.3 | 6.3 | 0.0 | 0.0 | 0.04 | |
| C2 | M | n | 0 | 90 | 85 | 63 | 58 | 104 | 77 | 68 | 57 | 64 | 78 | $\chi 2$=12.861, $p$=0.200 |
| | | % | 0.0 | 98.9 | 96.6 | 98.4 | 100.0 | 100.0 | 98.7 | 98.7 | 95.0 | 97.0 | 100.0 | |
| | F | n | 0 | 1 | 3 | 1 | 0 | 0 | 1 | 1 | 3 | 2 | 0 | |
| | | % | 0.0 | 1.1 | 3.4 | 1.6 | 0.0 | 0.0 | 1.3 | 1.3 | 5.0 | 3.0 | 0.0 | |
| C3 | M | n | 0 | 77 | 82 | 60 | 52 | 93 | 78 | 56 | 47 | 62 | 72 | $\chi 2$=9.127, $p$=0.136 |
| | | % | 0.0 | 98.7 | 100.0 | 100.0 | 100.0 | 100.0 | 98.7 | 98.2 | 94.0 | 98.4 | 98.6 | |
| | F | n | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 1 | 1 | |
| | | % | 0.0 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.3 | 1.8 | 6.0 | 1.6 | 1.4 | |

*C1: Burns, scalds and frostbites; C2: Deviation due to electrical problems, explosion, fire; C3: Contact with electrical voltage, temperature, hazardous substances (M: Male, F:Female)*

A statistically significant difference was found in the gender analysis of fatal occupational accidents caused by fire in category C1 ($p$ = 0.005). On the other hand, no significant difference was found in categories C2 and C3.

## 5. DISCUSSION

This study highlights that the lack of institutional standardization in Türkiye's fire incident reporting system leads to the fragmentation of data across various public authorities, such as the SSI, AFAD, and local governments. This fragmentation limits the scientific representation of national fire safety statistics. Due to this methodological inconsistency, significant discrepancies arise between official data and findings obtained from the media and NGOs. This situation hinders the comprehensive analysis of industrial risks and the development of preventive strategies. These uncertainties in the data sets constitute a structural barrier to establishing a monitoring capacity that is internationally comparable, transparent, and evidence-based. Consequently, the absence of a centralized data infrastructure disconnects national fire safety management from a data-driven foundation (RQ1). Despite this structural issue, the Presidency of Strategy and Budget (2023) presents a solution-oriented plan through steps taken under the Twelfth Development Plan (2024–2028) [57, 58]. The Occupational Health and Safety Working Group established under the plan is conducting work to prevent workplace accidents and occupational diseases. Within this scope, the focus has been on priority areas such as the standardization of indicators, the modernization of record-keeping systems, and the promotion of domestic equipment production. In particular, the development of data-driven monitoring systems in high-risk sectors is targeted, and these initiatives are expected to play a critical role in addressing the national data gap [59].

Despite shortcomings in the national data infrastructure (RQ1), analyses based on SSI data reveal that industrial fire risks in Türkiye exhibit a systematic and persistent pattern. The findings indicate that fire-related incidents account for approximately 5–6% of all workplace accidents. Notably, in the analysis of fatal cases (Figure 5), the observed increase in Category C2 is striking, despite changes in working conditions brought about by the COVID-19 pandemic. This situation confirms that fire risks are not limited to direct burns alone; they impose a continuous burden on occupational health through secondary yet fatal effects such as smoke inhalation, exposure to toxic gases, and physiological stress [39, 60–68].

On the other hand, when considering periods of incapacity, an upward trend was identified in the C1 and C3 categories (Figure 4) [56]. These data concretely illustrate how critical the need for "data-driven monitoring systems" and "improved record-keeping systems"—targeted in the Twelfth Development Plan—truly is. Although the current findings do not establish a definitive causal relationship, they

demonstrate that standardizing fire safety management at the national level and grounding it in a comprehensive database is essential to breaking this persistent accident pattern.

Statistical analyses have revealed significant differences in industrial fire incidents in Türkiye based on gender and sector (RQ3). Despite the low incidence rate, the data indicate a systematic continuity over the years (RQ2). In particular, the high incidence of accidents among male workers can be attributed to the high concentration of employment in high-risk sectors such as heavy industry and petrochemicals [69]. These data indicate that fires stem not from isolated accidents but from structural weaknesses in production processes, safety culture, and institutional control mechanisms [69–71].

On a global scale, the Global Fire Management Center, established through a partnership between the Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), and the Global Fire Monitoring Center (GFMC), the G7 countries' the Kananaskis Forest Fire Condition, UNEP's "Fire Ready Formula" approach, the Transboundary Haze Pollution Agreement signed by the Association of Southeast Asian Nations (ASEAN), and the European Union's Civil Protection Mechanism, strive to ensure data standardization and coordination; however, the lack of an integrated "global fire action plan" persists [72–75]. In this context, the local findings from our study have been synthesized with global solution efforts to propose the "Multi-Layered Fire Safety Model" in Figure 8. In the proposed model, technological, organizational, and human elements are structured as mutually reinforcing layers.

These structural and operational solutions sought in the global literature, when combined with the analysis of local statistical data obtained in our study, have concretized the need for a comprehensive intervention framework. Accordingly, based on the risk patterns identified in the analyzed data, the Multi-Layered Fire Safety Model presented in Figure 8 is proposed as a conceptual solution framework that minimizes global deficiencies while managing local risks. In particular, the prevalence and persistence of fatal accidents in the statistical findings presented in category C2, along with the demographic patterns identified in the analysis, highlight systemic safety vulnerabilities. Technological monitoring and IoT-based solutions are needed to prevent accidents. The persistent nature of accidents over the years necessitates strengthening the emergency response and risk awareness layers. Addressing data gaps and thus the need for a centralized digital database are clearly demonstrated for the effectiveness of this layer. Gender differences indicate the need to integrate sectoral risk management and workforce policies into the model. In summary, this model transforms statistical patterns of accidents and risks in the data into a layered security strategy.

The model's objective is sustainable industrial safety. It argues that this can be achieved not only through technological modernization but also through a synthesis of coordinated data management, policy continuity, and human-centered design. In the management model, technological, organizational, and human elements are structured as mutually reinforcing layers. The model is based on an Occupational Safety and Health (OSH) system consistent with the literature. The second layer of the structure consists of advanced technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), and digital twins [76–81]. Studies in the literature show that AI-based monitoring systems achieve an 85% success rate in early fire detection. VR/AR-supported training has been shown to reduce emergency response times by 30% [82–84]. Furthermore, when local data is integrated into global prevention systems, the system can become fully compliant with the Seveso/eMARS directives. In the face of the growing threat of the climate crisis, early warning systems compliant with international standards must be adopted. At this point, ensuring data transfer in accordance with EU and OECD standards is of utmost importance. This process requires interdisciplinary coordination among institutions such as SSI, AFAD, and local governments [7, 17].

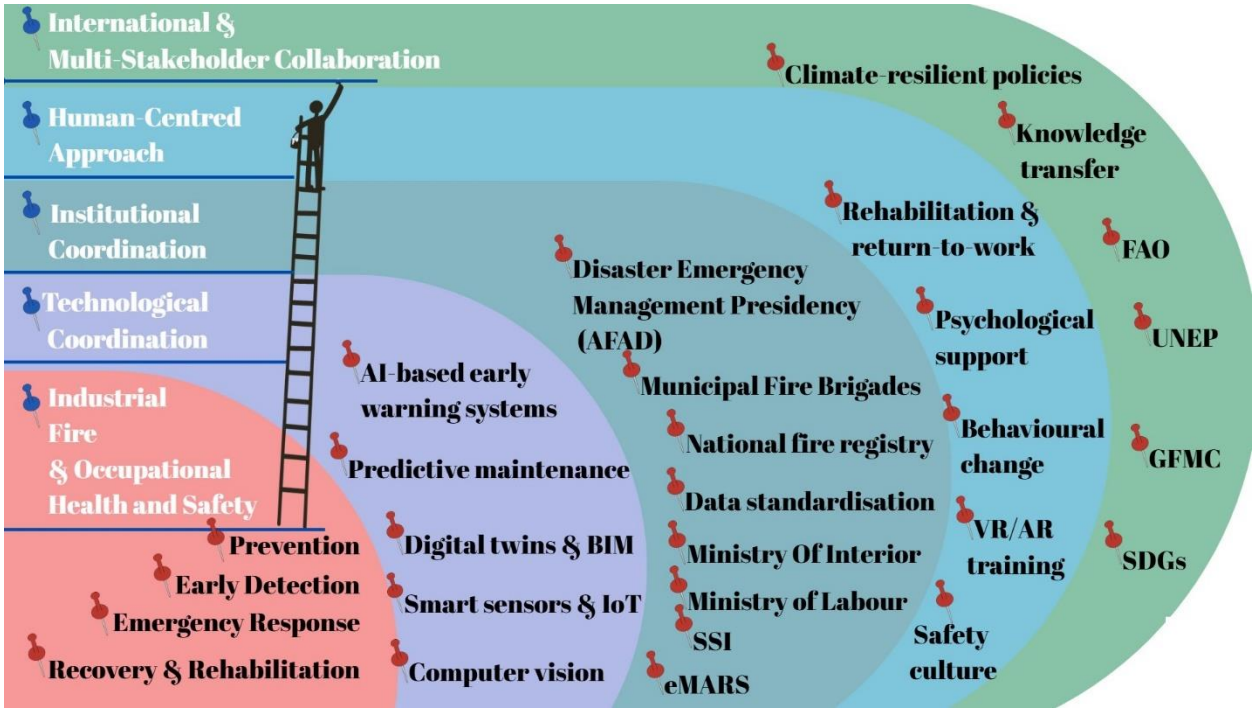



***Figure 8.*** *Multilayered fire safety models*

In addition to all this technological and organizational coordination, the system's operation is based on the principle of "risk-based prioritization." In line with the concept of the welfare state, it must place people at the center. The model should also include monitoring the rehabilitation processes of burn victims and standardizing return-to-work programs. This approach can minimize labor force loss while enhancing social resilience [66, 67]. Through the combination of data coordination and human-centered design, it can ensure safe production policies and accelerate industrial modernization. This holistic approach can strengthen Türkiye's integration with international safety standards while also solidifying its global safety reputation. Industrial fire safety is a multidimensional governance issue ranging from occupational health to economic sustainability. Consequently, despite its theoretical soundness, this model may impose cost constraints on small-scale businesses [72–74].

## 6. CONCLUSION AND RECOMMENDATIONS

The most important contribution of this study is to highlight the limitations of existing data and to demonstrate the need for a nationally standardized fire database in Türkiye. Findings based on SSI annual reports show that the proportion of fire-related occupational accidents within the total number of occupational accidents is relatively low. However, a relatively stable trend has been observed in fire-related occupational accidents over the years. Unfortunately, existing reports do not allow for direct linkage to sectoral and structural factors. This clearly reveals the lack of a centralized and integrated data infrastructure for industrial fires.

Therefore, the findings of this study should be evaluated not as definitive conclusions, but as exploratory evidence indicating the steps needed to improve the current system. The Multilayered Fire Safety Model proposed in this study synthesizes empirical findings with approaches in the literature, offering a holistic framework that combines technological modernization, data management, policy continuity, and human-centered design. Furthermore, this model can provide a framework fully aligned with United Nations Sustainable Development Goals (SDGs) 3, 8, 9, and 13.

In conclusion, fire safety is a complex management issue requiring multi-layered solutions. While explicitly acknowledging current data limitations, this study aims to provide an academic foundation for discussions regarding the development of a more comprehensive and preventive fire safety system in Türkiye. The findings provide guidance for policymakers and practitioners. The establishment of a transparent,

centralized national fire data monitoring system that complies with international standards should be considered a strategic priority.

## DECLARATION OF ARTIFICIAL INTELLIGENCE (AI) USE

When drafting the manuscript, neither generative AI agents nor large language models (LLMs) were used in any aspect of the study.

## CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

## REFERENCES

[1] Brzezińska, D., and Bryant, P., "Risk index method—a tool for building fire safety assessments", Applied Sciences, 11(8): 3566, (2021). DOI: https://doi.org/10.3390/app11083566

[2] Daéid, N.N., "Fire Investigation", CRC Press, First Edition, (2004). DOI: https://doi.org/10.1201/9780203646953

[3] Planas, E., Paugam, R., Àgueda, A., Vacca, P., and Pastor, E., "Fires at the wildland-industrial interface: Is there an emerging problem?", Fire Safety Journal, 141: 103906, (2023). DOI: https://doi.org/10.1016/j.firesaf.2023.103906

[4] Çelik, İ.H., Usta, G., Yılmaz, G., and Yakupoğlu, M., "An assessment on the technological disasters experienced in Türkiye (between the years of 2000–2020)", Artvin Coruh University International Journal of Social Sciences, 6(2): 49-57, (2020). DOI: https://doi.org/10.22466/acusbd.776580

[5] Qiao, Y., Lam, C.C., Zhong, H., Pan, M., Zhang, T., and Wong, M.O., "BIM and GIS-integrated multi-stakeholder fire risk assessment model for heritage buildings", International Journal of Disaster Risk Reduction, 105983, (2025). DOI: https://doi.org/10.1016/j.ijdrr.2025.105983

[6] Omidvari, F., Jahangiri, M., Mehryar, R., Alimohammadlou, M., and Kamalinia, M., "Fire risk assessment in healthcare settings: Application of FMEA combined with multi-criteria decision making methods", Mathematical Problems in Engineering, 2020: 8913497, (2020). DOI: https://doi.org/10.1155/2020/8913497

[7] Bertazzi, P.A., Bernucci, I., Brambilla, G., Consonni, D., and Pesatori, A.C., "The Seveso studies on early and long-term effects of dioxin exposure: A review", Environmental Health Perspectives, 106(Suppl 2): 625-633, (1998). DOI: https://doi.org/10.1289/ehp.98106625

[8] CTIF Center of Fire Statistics, "World Fire Statistics Report No. 30", (2023). [https://ctif.org/news/world-fire-statistics-report-no-30-comprehensive-analysis-fire-statistics-2023]. Access date: 26 April 2024

[9] Manes, M., Houssami, M.E., Campbell, R., Sauca, A., Rush, D., Hofmann, A., Wagner, P., Sokolov, S., Leene, M., Kobes, M., Oberhagemann, D., Rupp, N., Jomaas, G., Grone, F., and Guillaume, E., "Closing data gaps and paving the way for pan-European fire safety efforts: Part I—Overview of current practices for fire statistics", Fire Technology, 59(4): 1925-1968, (2023). DOI: https://doi.org/10.1007/s10694-023-01415-6

[10] Vignesh, K.S., Sathishkumar, A., Kim, S.C., Sowmya, N., and Arun, A., "Enhancing safety measures in manufacturing facilities: A comprehensive assessment of dust control and explosion mitigation systems", Process Safety and Environmental Protection, 201: 107479, (2025). DOI: https://doi.org/10.1016/j.psep.2025.107479

[11] Delforge, D., Wathelet, V., Below, R., Sofia, C.L., Tonnelier, M., van Loenhout, J.A., and Speybroeck, N., "EM-DAT: The emergency events database", BMC Public Health, 25: 105509, (2025). DOI: https://doi.org/10.1186/s12889-024-21026-2

[12] Girgin, S., and Yetiş, Ü., "Data availability in selected international databases on industrial accidents that occurred in Türkiye", Conference Paper, (2007). DOI: https://doi.org/10.13140/2.1.2046.2724

[13] Düzgün, H.S., and Leveson, N., "Analysis of Soma mine disaster using causal analysis based on systems theory (CAST)", Safety Science, 110: 37-57, (2018). DOI: https://doi.org/10.1016/j.ssci.2018.07.028

[14] Kurtulmuş, T.Ö., Yerlikaya-Özkurt, F., and Askan, A., "Modeling of kappa factor using multivariate adaptive regression splines: Application to the western Türkiye ground motion dataset", Natural Hazards, 120(8): 7817-7844, (2024). DOI: https://doi.org/10.1007/s11069-024-06535-y

[15] Alkış, S., Aksoy, E., and Akpınar, K., "Risk assessment of industrial fires for surrounding vulnerable facilities using a multi-criteria decision support approach and GIS", Fire, 4(3): 53, (2021). DOI: https://doi.org/10.3390/fire4030053

[16] Jakhar, R., Samek, L., and Styszko, K., "A comprehensive study of the impact of waste fires on the environment and health", Sustainability, 15(19): 14241, (2023). DOI: https://doi.org/10.3390/su151914241

[17] Laurent, A., Pey, A., Gurtel, P., and Fabiano, B., "A critical perspective on the implementation of the EU Council Seveso Directives in France, Germany, Italy and Spain", Process Safety and Environmental Protection, 148: 47-74, (2021). DOI: https://doi.org/10.1016/j.psep.2020.09.064

[18] Kirchsteiger, C., "Status and functioning of the European Commission's major accident reporting system", Journal of Hazardous Materials, 65(1-2): 211-231, (1999). DOI: https://doi.org/10.1016/S0304-3894(98)00264-7

[19] Bhusari, A., Goh, A., Ai, H., Sathanapally, S., Jalal, M., and Mentzer, R.A., "Process safety incidents across 14 industries", Process Safety Progress, 40(1): e12158, (2021). DOI: https://doi.org/10.1002/prs.12158

[20] Republic of Türkiye Official Gazette, "Law No. 6331 on Occupational Health and Safety", (2012). [https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=6331&MevzuatTur=1&MevzuatTertip=5]. Access date: 15 April 2025

[21] Republic of Türkiye Official Gazette, "Regulation on the Prevention and Mitigation of the Effects of Major Industrial Accidents (BEKRA)", 30702, 2 March 2019. [https://www.resmigazete.gov.tr/eskiler/2019/03/20190302-1.htm]. Access date: 24 July 2024

[22] Republic of Türkiye Official Gazette, "Regulation on Safety Data Sheets Concerning Hazardous Substances and Mixtures", (2014). [https://www.resmigazete.gov.tr/eskiler/2014/12/20141213-1.htm]. Access date: 11 October 2023

[23] Republic of Türkiye Official Gazette, "Waste Management Regulation", 29314, 2 April 2015. [https://www.resmigazete.gov.tr/eskiler/2015/04/20150402-2.htm]. Access date: 24 July 2024

[24] Republic of Türkiye Official Gazette, "Regulation on the Protection of Employees from the Dangers of Explosive Environments", 28633, 30 April 2013. [https://www.resmigazete.gov.tr/eskiler/2013/04/20130430-6.htm]. Access date: 24 July 2024

[25] Bottrill, G., Cheyne, D., Vijayaraghavan, G., and Mackay, S., "ATEX Directive", in Practical Electrical Equipment and Installations in Hazardous Areas, Newnes, (2005). DOI: https://doi.org/10.1016/B978-075066398-4/50016-1

[26] Republic of Türkiye Official Gazette, "Regulation on Equipment and Protective Systems Used in Potentially Explosive Atmospheres (2014/34/AB)", 29758, 30 June 2016. [https://resmigazete.gov.tr/eskiler/2016/06/20160630-13.htm]. Access date: 22 May 2026

[27] Shearman, M., "ATEX 100a Directive (94/9/EC)—Clarifying compliance", World Pumps, 457: 46-47, (2004). DOI: https://doi.org/10.1016/S0262-1762(04)00365-7

[28] Republic of Türkiye Official Gazette, "Regulation on Business Opening and Operating Licenses", 2005/9207. [https://csb.gov.tr/haberler/-isyeri-acma-ve-calisma-ruhsatlarina-iliskin-yonetmelik-degisti-302288]. Access date: 24 July 2024

[29] Savaşan, Z., and Sumer, V., "Environmental Law and Policies in Turkey", Springer International Publishing, (2020). DOI: https://doi.org/10.1007/978-3-030-36483-0

[30] Republic of Türkiye Official Gazette, "Regulation on Fire Protection of Buildings", 19 December 2007. [https://www.resmigazete.gov.tr/eskiler/2007/12/20071219-2.htm]. Access date: 24 July 2024

[31] Amyotte, P.R., "Some myths and realities about dust explosions", Process Safety and Environmental Protection, 92(4): 292-299, (2014). DOI: https://doi.org/10.1016/j.psep.2014.02.013

[32] Rein, G., "Smoldering combustion", in SFPE Handbook of Fire Protection Engineering, Springer, New York, (2016). DOI: https://doi.org/10.1007/978-1-4939-2565-0_19

[33] Salvador, D.C., "Welding safety and health: Occupational hazards and risk mitigation", International Journal of Advanced Research in Science, Communication and Technology, 993-997, (2023). DOI: https://doi.org/10.48175/IJARSCT-11904

[34] Skjold, T., Souprayen, C., and Dorofeev, S., "Fires and explosions", Progress in Energy and Combustion Science, 64: 2-3, (2018). DOI: https://doi.org/10.1016/j.pecs.2017.09.003

[35] Taveau, J., "Secondary dust explosions: How to prevent them or mitigate their effects?", Process Safety Progress, 31(1): 36-50, (2012). DOI: https://doi.org/10.1002/prs.10478

[36] Republic of Türkiye Official Gazette, "Regulation on the Classification, Labelling and Packaging of Substances and Mixtures", 28848, 11 December 2013. [https://ekutuphane.csgb.gov.tr/Media/m1xbymed/kimya-sekt%C3%B6r%C3%BC-isg-rehberi.pdf]. Access date: 24 July 2024

[37] Di, B., Xiang, L., Daoqing, Y., and Kaimin, P., "MARA-YOLO: An efficient method for multiclass personal protective equipment detection", IEEE Access, 12: 24866-24878, (2024). DOI: https://doi.org/10.1109/ACCESS.2024.3365504

[38] Antonioni, G., Spadoni, G., and Cozzani, V., "Application of domino effect quantitative risk assessment to an extended industrial area", Journal of Loss Prevention in the Process Industries, 22(5): 614-624, (2009). DOI: https://doi.org/10.1016/j.jlp.2009.02.012

[39] Ji, J., Tong, Q., Khan, F., Dadashzadeh, M., and Abbassi, R., "Risk-based domino effect analysis for fire and explosion accidents considering uncertainty in processing facilities", Industrial and Engineering Chemistry Research, 57(11): 3990-4006, (2018). DOI: https://doi.org/10.1021/acs.iecr.8b00103

[40] Kadri, F., Chatelet, E., and Lallement, P., "The assessment of risk caused by fire and explosion in chemical process industry: A domino effect-based study", Journal of Risk Analysis and Crisis Response, 3(2): 66-74, (2013). DOI: https://doi.org/10.2991/jrarc.2013.3.2.1

[41] Zhang, Z., Larranaga, A.S., and Wang, Q., "Liquefied natural gas storage and transmission", in Advances in Natural Gas: Formation, Processing, and Applications, Volume 6, Elsevier, 51-80, (2024). DOI: https://doi.org/10.1016/B978-0-443-19225-8.00009-3

[42] Anadolu Agency, "Tuzla industrial fire by domino effect", https://www.aa.com.tr/tr/gundem/tuzlada-fabrikada-cikan-yangina-itfaiye-mudahale-ediyor/3252587. Access date: 29 April 2024

[43] Hunt, J.P., Calvert, C.T., Peck, M.D., and Meyer, A.A., "Occupation-related burn injuries", Journal of Burn Care and Rehabilitation, 21(4): 327-332, (2000). DOI: https://doi.org/10.1097/00004630-200021040-00007

[44] Siraj, M.T., Debnath, B., Payel, S.B., Bari, A.B.M.M., and Islam, A.R.M.T., "Analysis of the fire risks and mitigation approaches in the apparel manufacturing industry: Implications toward operational safety and sustainability", Heliyon, 9(9): e20312, (2023). DOI: https://doi.org/10.1016/j.heliyon.2023.e20312 MT Siraj,

[45] Topyay, G., and Büyüker, S.M., "A retrospective analysis of the causes of industrial fires in Istanbul occurring between 2015 and 2020", Afet ve Risk Dergisi, 7(2): 392-409, (2024). DOI: https://doi.org/10.35341/afet.1360896

[46] Li, G., Guo, J., Kang, Y., Huang, Q., Zhao, J., and Liu, C., "Classification and prevention of electrical fires: A comprehensive review", Fire, 8(4): 154, (2025). DOI: https://doi.org/10.3390/fire8040154

[47] Kumar, K.S., and Balachander, K., "Fire risks in electrical installations: The review", in E3S Web of Conferences, 376: 01113, (2023). DOI: https://doi.org/10.1051/e3sconf/202337601113

[48] Dettmeyer, R.B., "Heat, fire, electricity, lightning, radiation, and gases", in Forensic Histopathology: Fundamentals and Perspectives, Springer International Publishing, 187-206, (2018). DOI: https://doi.org/10.1007/978-3-319-77997-3_7

[49] Toolaroud, P.B., Attarchi, M., Haghdoust, R.A., Feizkhah, A., Esmailzadeh, M., Rimaz, S., Pirooz, A., and Mobayen, M., "Epidemiology of work-related burn injuries: A ten-year retrospective study of 429 patients at a referral burn centre in the north of Iran", International Wound Journal, 20(9): 3599-3605, (2023). DOI: https://doi.org/10.1111/iwj.14238

[50] Dissanaike, S., and Rahimi, M., "Epidemiology of burn injuries: Highlighting cultural and socio-demographic aspects", International Review of Psychiatry, 21(6): 505-511, (2009). DOI: https://doi.org/10.3109/09540260903340865

[51] Brych, S. B., Engrav, L. H., Rivara, F. P., Ptacek, J. T., Lezotte, D. C., Esselman, P. C., Kowalske, K.J., and Gibran, N. S. "Time off work and return to work rates after burns: Systematic review of the literature and a large two-center series", Journal of Burn Care and Rehabilitation, 22(6): 401-405, (2001). DOI: https://doi.org/10.1097/00004630-200111000-00010

[52] Ehde, D.M., Patterson, D.R., Wiechman, S.A., and Wilson, L.G., "Post-traumatic stress symptoms and distress 1 year after burn injury", Journal of Burn Care and Rehabilitation, 21(2): 105-111, (2000). DOI: https://doi.org/10.1097/00004630-200021020-00005

[53] Chouinard, N.H., Ndongo Sonfack, D.J., Chang, S.L., Bergeron, F., Beaudoin Cloutier, C., and Guertin, J.R., "Exploring the prevalence of post-traumatic stress disorder and post-traumatic stress symptoms in parents within 12 months of child burn injury: A systematic review", Journal of Burn Care and Research, 45(4): 1051-1059, (2024). DOI: https://doi.org/10.1093/jbcr/irae033

[54] Organized Industrial Zones Supreme Organization, "Approved Organized Industrial Zones in Türkiye", https://osbuk.org/wp-content/uploads/2021/05/353-OSB.pdf. Access date: 10 October 2025

[55] TMMOB Kimya Mühendisleri Odası İstanbul Şubesi, "Endüstriyel Yangınlar ve Patlamalar Raporu", (2022). https://www.kmo.org.tr/resimler/ekler/bf75f1541e47b5c_ek.pdf . Access date: 27 April 2027

[56] Social Security Institution, "Social Security Institution Annual Statistics 2022", https://www.sgk.gov.tr/Istatistik/Yillik/fcd5e59b-6af9-4d90-a451-ee7500eb1cb4/. Access date: 27 April 2027

[57] General Directorate of Occupational Health and Safety, "General Directorate of Occupational Health and Safety Strategic Plan 2022–2023", Ministry of Labour and Social Security Publications, Ankara, (2023). https://www.csgb.gov.tr/Media/szkblgtl/stratejik-plan-2022-2023.pdf

[58] Ministry of Labour and Social Security, "Ministry of Labour and Social Security Strategic Plan 2024–2028", ÇSGB Publications, Ankara, (2024). https://www.csgb.gov.tr/Media/zroe5pul/%C3%A7sgb-stratejik-plan%C4%B1-2024-2028.pdf

[59] Presidency of Strategy and Budget, "Twelfth Development Plan (2024–2028): Occupational Health and Safety Working Group Report", Presidency of Strategy and Budget Publications, Ankara, (2023). https://onikinciplan.sbb.gov.tr/calisma-gruplari-listesi/is-sagligi-ve-guvenligi/

[60] Qu, X., Dong, H., Tan, X., and Li, Z., "Real-time fire detection and response system using machine vision for industrial safety", International Journal of Modern Physics C, 2542004, (2025). DOI: https://doi.org/10.1142/S0129183125420045

[61] Tauseef, S., Abbasi, T., Pompapathi, V., and Abbasi, S., "Case studies of 28 major accidents of fires/explosions in storage tank farms in the backdrop of available codes/standards/models for safely configuring such tank farms", Process Safety and Environmental Protection, 120: 340-358, (2018). DOI: https://doi.org/10.1016/j.psep.2018.09.017

[62] Chavan, A., Chopde, A., Barde, A., and Wagaj, S., "Automated fire suppression system for electrical panel enclosures using IoT and embedded system", in 2025 International Conference on Emerging Smart Computing and Informatics (ESCI), IEEE, 1-6, (2025). DOI: https://doi.org/10.1109/ESCI63694.2025.10988330

[63] Lee, J. H., Kim, Y., Kim, I., Hong, S. B., and Yun, H. S., "Comparative analysis of ultrasonic and traditional gas-leak detection systems in the process industries: A Monte Carlo approach", Processes, 12(1): 67, (2023). DOI: https://doi.org/10.3390/pr12010067

[64] Lari, M., "A longitudinal study on the impact of occupational health and safety practices on employee productivity", Safety Science, 170: 106374, (2024). DOI: https://doi.org/10.1016/j.ssci.2023.106374

[65] European Agency for Safety and Health at Work, "Occupational safety and health indicators: A review of methodologies", (2021). https://osha.europa.eu. Access date: 24 July 2024

[66] Kaufman, M. S., Graham, C. C., Lezotte, D., Fauerbach, J. A., Gabriel, V., Engrav, L. H., and Esselman, P. "Burns as a result of assault: Associated risk factors, injury characteristics, and outcomes", Journal of Burn Care and Research, 28(1): 21-28, (2007). DOI: https://doi.org/10.1097/BCR.0B013E31802C896F

[67] Dyster-Aas, J., Kildal, M., Willebrand, M., Gerdin, B., and Ekselius, L., "Work status and burn specific health after work-related burn injury", Burns, 30(8): 839-842, (2004). DOI: https://doi.org/10.1016/j.burns.2004.05.010

[68] Dissanaike, S., Boshart, K., Coleman, A., Wishnew, J., and Hester, C. "Cooking-related pediatric burns: Risk factors and the role of differential cooling rates among commonly implicated substances", Journal of Burn Care and Research, 30(4): 593-598, (2009). DOI: https://doi.org/10.1097/BCR.0b013e3181ac02c8

[69] World Health Organization, "Occupational Health: A Manual for Primary Health Care Practitioners", WHO Publications, Geneva, (2023). https://iris.who.int/items/a47706a9-6281-45f7-8e51-a49113406e00

[70] Murray, C.J.L., Lopez, A.D., and WHO Global Burden of Disease Study Group, "Measuring the global burden of disease: DALYs and healthy life expectancy", The Lancet, 396: 1223-1249, (2020). DOI: https://doi.org/10.1016/S0140-6736(20)30925-9

[71] Jeddi, M.Z., Hopf, N.B., Louro, H., Viegas, S., Galea, K.S., Pasanen-Kase, R., …and Bessems, J., "Developing human biomonitoring as a 21st century toolbox within the European exposure science strategy 2020–2030", Environment International, 168: 107476, (2022). DOI: https://doi.org/10.1016/j.envint.2022.107476

[72] Burkart, S., Baca, M.F.D., Lerma, L.M., and Ángel, N.T., "Impacts of sustainable cattle farming on the 2030 agenda: A global review", Agricultural Systems, 234: 104649, (2026). DOI: https://doi.org/10.1016/j.agsy.2026.104649

[73] Bloem, S., Cullen, A.C., Mearns, L.O., and Abatzoglou, J.T., "The role of international resource sharing arrangements in managing fire in the face of climate change", Fire, 5(4): 88, (2022). DOI: https://doi.org/10.3390/fire5040088

[74] Fraccaroli, C., Górriz-Mifsud, E., Varela, E., and Wunder, S., "Economic incentives for reducing wildfire risk: Taking stock of an emerging field", Journal of Environmental Management, 397: 128296, (2026). DOI: https://doi.org/10.1016/j.jenvman.2025.128296

[75] European Commission, "Wildfires and the EU Civil Protection Mechanism", Civil Protection and Humanitarian Aid Operations, (2024). https://civil-protection-humanitarian-aid.ec.europa.eu. Access date: 24 July 2024

[76] Fang, Q., Ding, L., Zhong, B., Love, P.E.D., Luo, H., and Pena-Mora, F., "Computer vision applications in construction safety: A systematic review", Safety Science, 110: 213-225, (2018). DOI: https://doi.org/10.1016/j.ssci.2018.04.025

[77] Lee, G., Kim, Y., and Teizer, J., "Vision-based safety monitoring in construction: A systematic review of deep learning methods", Automation in Construction, 154: 104094, (2023). DOI: https://doi.org/10.1016/j.autcon.2023.104094

[78] Lo, C.K., Hu, H., and Chan, A.P.C., "Automatic detection of construction PPE using YOLOv7: A field evaluation", Sustainability, 14(23): 15987, (2022). DOI: https://doi.org/10.3390/su142315987

[79] Liu, R., Zhang, W., and Li, X., "Real-time PPE detection for construction workers using improved YOLOv7", Buildings, 14(7): 1623, (2024). DOI: https://doi.org/10.3390/buildings14071623

[80] Vukicevic, A.M., Petrovic, M., Milosevic, P., Peulic, A., Jovanovic, K., and Novakovic, A., "A systematic review of computer vision-based personal protective equipment compliance in industry practice: Advancements, challenges and future directions", Artificial Intelligence Review, 57(12): 319, (2024). DOI: https://doi.org/10.1007/s10462-024-10978-x

[81] Damilos, S., Saliakas, S., Karasavvas, D., and Koumoulos, E.P., "An overview of tools and challenges for safety evaluation and exposure assessment in Industry 4.0", Applied Sciences, 14(10): 4207, (2024). DOI: https://doi.org/10.3390/app14104207

[82] Bao, Y., Li, H., and Zhang, C., "Virtual and augmented reality for construction safety training: A review", Automation in Construction, 135: 104102, (2022). DOI: https://doi.org/10.1016/j.autcon.2022.104102

[83] Patel, V., Chesmore, A., Legner, C.M., and Pandey, S., "Trends in workplace wearable technologies and connected-worker solutions for next-generation occupational safety, health, and productivity", Advanced Intelligent Systems, 4(1): 2100099, (2022). DOI: https://doi.org/10.1002/aisy.202100099

[84] Leong, L.K., Manickam, L., Haque, R., Jumbulingam, K., and Noordin, N.B.M., "Embracing digital transformation for sustainable business in the construction industry", Pakistan Journal of Life and Social Sciences, 22(2), (2024). DOI: https://doi.org/10.57239/PJLSS-2024-22.2.00113