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# A short review on polycyclic aromatic hydrocarbons (PAHs) emission from common daily living activities

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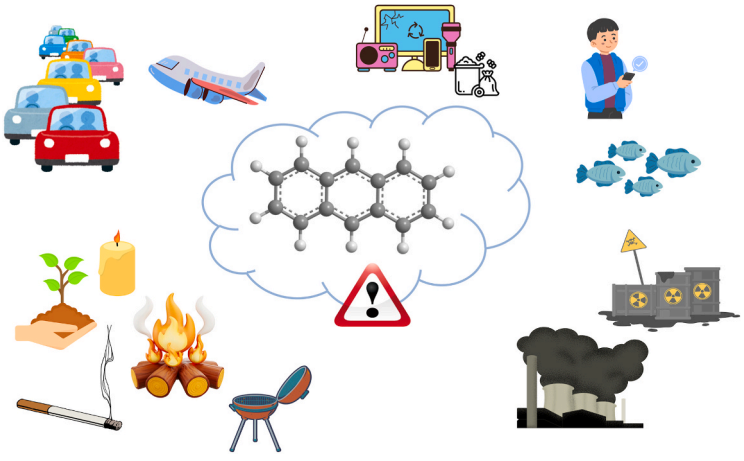
## HIGHLIGHTS

- Polycyclic Aromatic Hydrocarbons (PAHs) are ubiquitous pollutants.
- Most people are unaware of the activities in which PAHs are formed.
- The data presented are of interest for engineers (chemical, construction, industrial).
- Knowledge of the sources should encourage everyone to modify their lifestyles.
- Isomeric ratios are suggested to establish the natural and anthropic sources.

## GRAPHICAL ABSTRACT



## ABSTRACT

Polycyclic aromatic hydrocarbons (PAHs) are molecules of great interest because of their carcinogenic, teratogenic and toxic properties. The presence and distribution of PAHs in the environment is largely a product of the incomplete combustion of organic materials (petroleum, oil, coal and wood). A very small percentage of PAHs in the environment can be linked to natural causes, such as volcanic activity and forest fires. This review examines articles on most of the known sources of polycyclic aromatic hydrocarbons published in scientific journals over the past 10 years. In addition to the sources, the review also considers possible strategies for limiting the production of PAHs and some degradation methods using enzymes, bacteria and fungi. The data presented are certainly of interest both to researchers working in the scientific field and to designers and engineers (chemical, construction, industrial) who could draw inspiration from them in the design of new production processes and industrial plants. It is also recommended for *Earth Condominiums* to understand the activities to which they are exposed daily and the products they consume. A critical reading of the aforementioned sources should encourage everyone to potentially change their lifestyles and highlight the need for effective remediation strategies.

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## 1. Introduction

The idea for this review arose from the recent election of the Pope, on that occasion, the cardinals gathered in conclave used smoke signals (white and black) in order to communicate the result of the election to the world (Soda et al., 2025). Black smoke (indicating failure to elect) is produced using a mixture of potassium perchlorate, anthracene (a polycyclic aromatic hydrocarbon) and sulphur, while white smoke (indicating a successful election) is produced using a mixture of potassium chlorate, lactose and rosin. On the other hand, that result in the production of polycyclic aromatic hydrocarbons (PAHs) often escape attention or do not receive due consideration. Polycyclic aromatic hydrocarbons are organic compounds consisting of two or more condensed aromatic rings. The structures and the abbreviations of the most important PAHs are shown in Fig. 1

At room temperature and atmospheric pressure, PAHs are colorless or yellowish solids. In most cases, their vapor pressure is low and decreases as their molecular weight (number of rings) increases. Compounds with a low molecular mass tend to sublimate, as in the case of naphthalene, which was used in the past as a moth repellent for clothes. PAHs are characterized by high thermal stability, therefore, they often resist to the complete decomposition under usual combustion conditions (Dong et al., 2023). In recent years, several studies were performed to identify their sources in environmental and food matrices and in organisms or parts of them (Anonimed, 2024; Indelicato, 2022). Anthropogenic sources such as vehicles, heating and power plants, industrial processes, waste disposal and open burning constitute the main environmental sources. In rare cases, PAHs may have a biogenic origin, as evidenced by the presence of perylene derived from biogenic precursors (Aizenshtat, 1973). The main sources of polycyclic aromatic hydrocarbons are fossil fuels such as oil, coal and oil shale. Crude petroleum, which is formed from the decay of vegetation over millions of years, contains high concentrations of alkyl-substituted PAHs. Coal tar and petroleum residues also contain high percentages of PAHs. These compounds are also a major by-product of the incomplete combustion of fossil fuels and organic matter (e.g. coal and wood burning, internal combustion, etc.). Fig. 2 shows a diagram of the main sources of PAHs

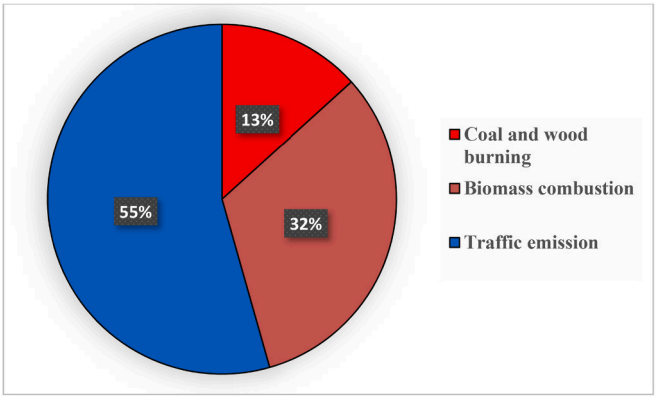


**Fig. 2.** Main sources of PAHs (Shi et al., 2021).

(Shi et al., 2021).

The mechanisms of PAHs formation (Fig. 3) during incomplete combustion processes or the pyrolysis of organic material are not yet

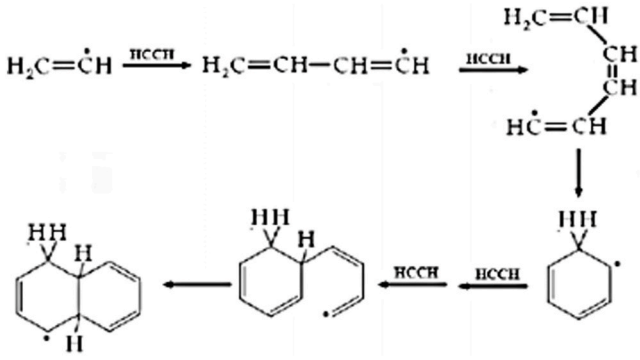


**Fig. 3.** Reactions of formation of PAHs through combustion processes (pyrosynthesis).

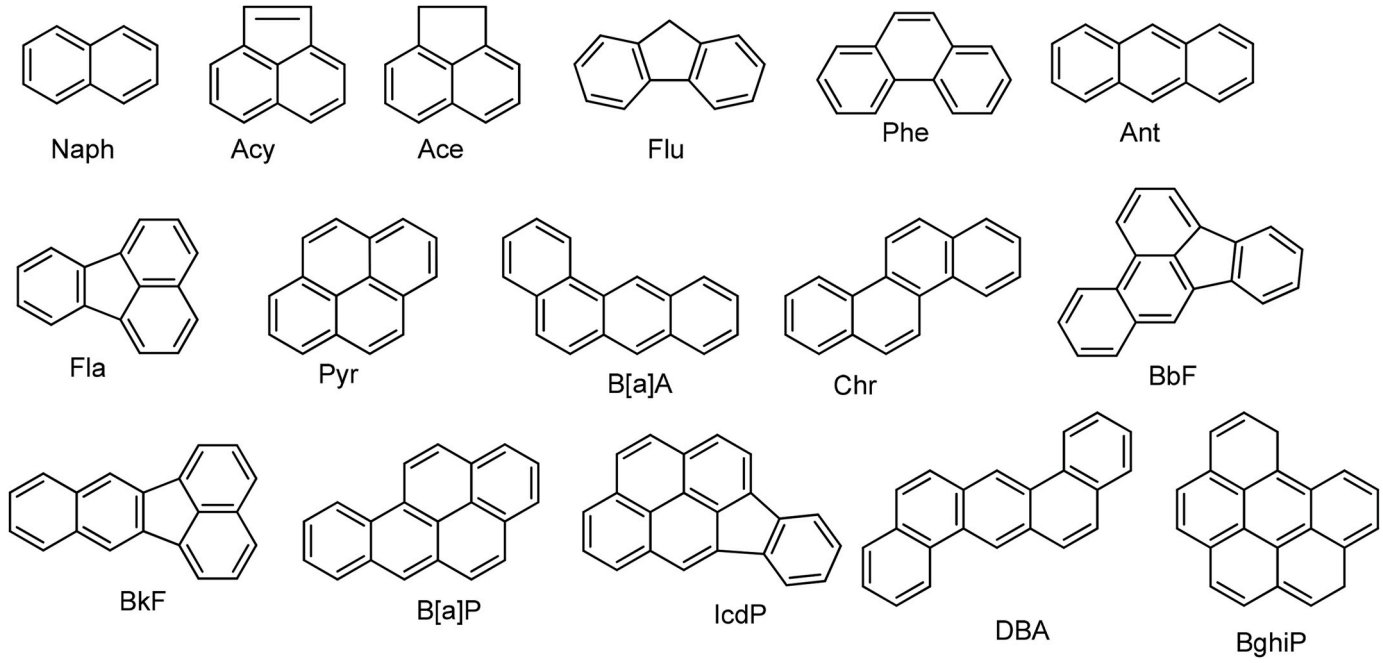


**Fig. 1.** Abbreviations of 16 EPA target PAHs: Naphthalene [Naph], Acenaphthylene [Acy], Acenaphthene [Ace], Fluorene [Flu], Phenanthrene [Phe], Anthracene [Ant], Fluoranthene [Fla], Pyrene [Pyr], Benzo[a]anthracene [B[a]A], Chrysene [Chr], Benzo[b]fluoranthene [BbF], Benzo[k]fluoranthene [BkF], Benzo[a]pyrene [B[a]P], Indeno [1,2,3-c,d]pyrene [IcdP], Dibenzo[a,h]anthracene [DBA], and Benzo[g,h,i]perylene [BghiP].

fully understood (B.R.T, S., 1998), but it can be hypothesized that, when pyrolysis occurs at high temperatures (650-900 °C) and in the absence of oxygen, $C_2H_2$ radical fragments are produced, which subsequently react with acetylene molecules. The result of this reaction is another four-carbon radical, which in turn can add another acetylene molecule and form a six-carbon ring. At this point, the hydrogen atom, bonded to the carbon of $CH_2$, can detach, giving rise to a benzene molecule, or add other acetylene molecules, giving rise to side chains that form further condensed benzene rings.

In the determination of the different sources (Baumard et al., 1999), fortunately, the presence of specific compounds and their concentration ratios can be used. Ant/(Ant + Phe) ratio <0.10 is usually an indication of low-temperature sources (petroleum), while a ratio >0.10 indicates a predominance of combustion (Anonimed, 2014a, 2014b; Bianchini and Bonsignore, 2016; Anonimed, 2005 ). Generally, for environmental matrices (sediments, organisms, water, air, etc.), the Fla/(Fla + Pyr) ratio is less than 0.50 for most petroleum samples and for gasoline, diesel, and fuel oil combustion, and greater than 0.50 in grass, coal, and wood combustion samples. The limiting ratio for petroleum appears closer to 0.40 than 0.50 for Fla/(Fla + Pyr), and ratios between 0.40 and 0.50 are more characteristic of liquid fossil fuel combustion, while ratios >0.50 are characteristic of grass, wood, or coal combustion. Literature data (Neff, 1979; Yunker et al., 2002) suggest that B[a]A/(B[a]A + Chr) ratios <0.20 involve petroleum, 0.20 to 0.35 indicate petroleum or combustion and >0.35 imply combustion, IP/(IP + BghiP) ratios of 0.20 most likely imply petroleum origin, 0.20 to 0.50 liquid fossil fuel combustion (vehicles and crude oil), and ratios >0.50 imply grass, wood, and coal combustion. In some cases, the values of the four ratios do not agree with each other and, considering that, generally, the sources of PAHs in a matrix can be different and occasional, we calculated the total index (Anonimed, 2014a) (reduced to two pairs of isomers compared to previous works because the concentrations of different isomers are very low) as the sum of the individual indices (discussed above) respectively normalized by the cutoff value (low-temperature sources - high-temperature sources) reported in the literature (Neff, 1979; Yunker et al., 2002).

$$Total\ index = \frac{1}{0.4}\frac{Fl}{(Fla+Pyr)} + \frac{1}{0.2}\frac{Ant}{(Ant+Ph)}$$

When the total index is > 2, we consider PAHs coming mainly from high-temperature processes (combustion), while lower values indicate mainly low-temperature sources (petroleum products). The relative abundance of high molecular weight PAHs, along with the isomeric ratios of PAHs, was used by researchers (Anonimed, 2014a) to determine the causes of the sinking of an ancient ship (the Scauri wreck). Specifically, they demonstrated that the presence of PAHs in wooden archaeological material was determined by high-temperature processes (combustion). The total index proposed by the authors, in this case, allowed them to determine the predominant sources of PAHs. Knowledge of the cause of the ancient ship's sinking could be of fundamental interest to archaeologists, restorers, and museum curators in order to adopt the most appropriate treatment for the specific case study. Other authors (R. Li, Hua, Zhang and Krebs, 2020a) use the positive matrix factorization (PMF) receptor model, the Unmix receptor model, and principal component analysis with multiple linear regression (PCA-MLR) to establish the PAHs sources. Researchers have turned their attention to this class of compounds from analytical, environmental and toxicological points of view because they are ubiquitous pollutants which makes highly lipophilic, making them bioaccumulative (Anonimed, 2024; Antonelli et al., 2024). Indeed, PAHs were found in animals (Anonimed, 2024), plants (L. Culotta and Melati, 2002), food and humans (Asamoah et al., 2019). Foods containing oils and fats are particularly susceptible to contamination by these substances due to their lipophilic nature and the widespread presence of these compounds in the environment. Furthermore, contamination can occur at various stages of production. Fig. 4 shows a simple scheme of biomagnification (see Fig. 5).

Human exposure to PAHs, like many other hazardous materials (heavy metals, pesticides, phthalates, etc.) (Anonimed, 2023; Indelicato, 2022), may occur through: breathing contaminated air (vehicle exhaust, cigarette smoke, fires, cleaning fireplaces and wood-burning stoves, etc.); ingestion of contaminated foods (smoked foods, grilled meat and fish, foods produced in contaminated soil or areas, contaminated water, etc.); skin contact (contaminated soil or sediment, carbon residue from stoves and fireplaces, creosote-treated materials). In some cases, multiple exposure routes may coexist. The health risk levels related to the different routes of PAH intake can be calculated by using equations that take into account various parameters (Balint et al., 2025). A recent study (Fu et al., 2025) has established the existence of interactions between micro plastics of aquatic environments and PAHs. Due to the small size and large surface area of the polymers, the concentrations of PAHs on the micro plastics exceeded those dissolved in the corresponding aqueous matrix by several orders of magnitude, increasing the bioaccumulation process and, consequently, the health risk for exposed

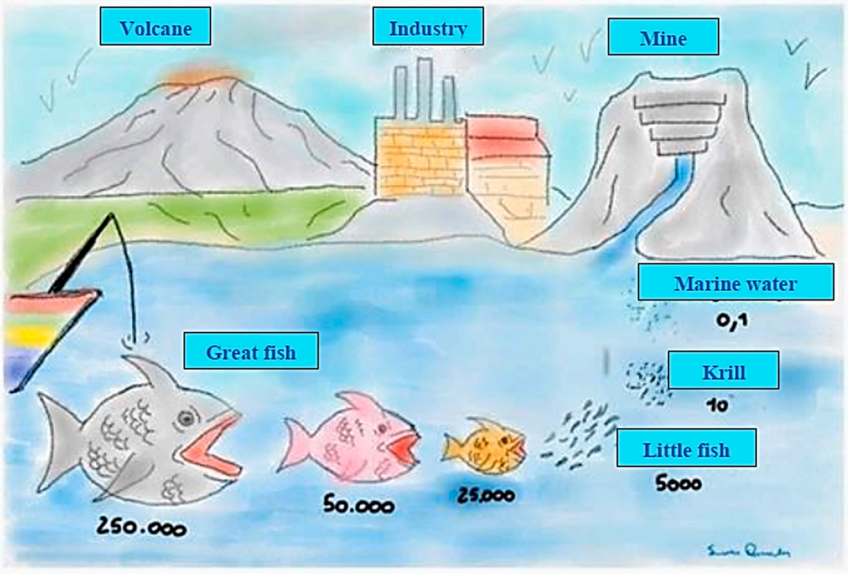


**Fig. 4.** Simple scheme of biomagnification.

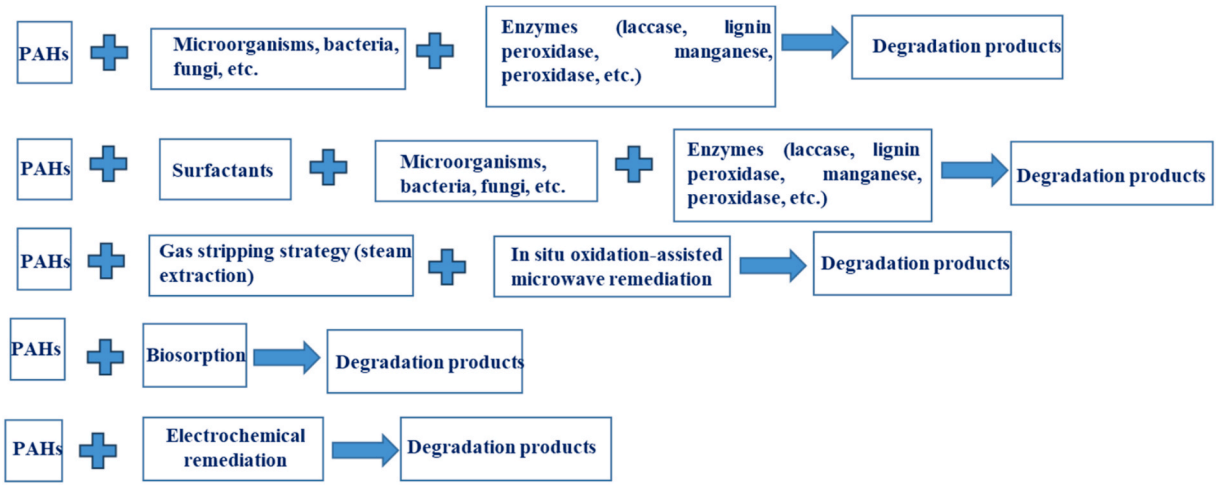


**Fig. 5.** Main remediation strategies used for PAH degradation.

organisms. Exposure to PAHs can result in illnesses and diseases, including oxidative stress, cell death, genetic mutations, systemic inflammation, and cardiovascular disorders. Even chronic exposure at low levels has been associated with an increased risk of cancer; lung and breast cancers are the most frequent malignant neoplasm.

The United States Agency for Toxic Substances and Disease Registry (ATSDR), the International Agency for Research on Cancer (IARC), and the United States Environmental Protection Agency (USEPA) have classified several PAHs as probable or possible human carcinogens (Sultan Hassan Alamri et al., 2021a,b). The USEPA considers seven compounds as priority compounds: dibenzo[a,h]anthracene, benzo[ghi] perylene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, and benzo[a]anthracene (Zelinkova and Wenzl, 2015). Therefore, knowledge of the possible common sources of this class of compounds is essential due to their physicochemical and toxicological characteristics. As early as 1979, the U.S. Environmental Protection Agency (USEPA) specified 16 preferred control PAHs (Table 1) (Si et al., 2023). The European Union (EU) has implemented legislation that sets maximum concentrations for PAHs in definite types of foods. In Commission Regulation (EU) 2023/915 of 25 April 2023, maximum residue concentrations are indicated for benzo[a]pyrene (as it is the most toxic) (10 μg $kg^{-1}$) and a limit value is established for the sum of: benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene and chrysene (50 μg $kg^{-1}$). The European Food Safety Authority (EFSA) names this group of PAHs as PAH4, considering them markers of carcinogenic potency in food products. It also proposes a PAH8 category, which includes four other compounds: benzo[k]fluoranthene, benzo[g,h,i]perylene, dibenzo[a,h] anthracene, and indeno[1,2,3-cd]pyrene. Many of the hazardous substances, including PAHs, are produced in indoor environment from common activities such as cooking cleaning and smoking, etc. (Valenti, 2016). Considering that people spend about 85% of their time in confined environments studies on indoor air quality are essential. It is therefore necessary to evaluate indoor contaminant concentrations and distributions in order to assess total human exposure to them. The aim of this review is to report the most significant contributions of the last ten years relating to polycyclic aromatic hydrocarbons deriving from common activities of daily living, in order to provide qualitative and quantitative information to assess human exposure to these hydrocarbons (see Tables 2, 3 and 4).

**Table 1**
IARC PAHs classification.

| Compound | IARC Classification | Compound | IARC Classification |
|---|---|---|---|
| Acenaphthene | **Not yet evaluated** | **Chrysene** | **3** |
| Acenaphthlene | **Not yet evaluated** | **Dibenz [a,h] anthracene** | **2A** |
| Anthracene | **3** | **Fluoranthene** | **3** |
| Benz[a] anthracene | **2A** | **Fluorene** | **3** |
| Benzo[b] fluoranthene | **2B** | **Indeno [g,h,i] perylene** | **2B** |
| Benzo[k] fluoranthene | **2B** | **Phenanthrene** | **3** |
| Benzo[g,h,i] perylene | **3** | **Pyrene** | **3** |
| Benzo[a]pyrene | **2A** | | |

IARC Classification:
Group 1: The agent is carcinogenic for humans
Group 2A: The agent is probably carcinogenic for humans
Group 2B: The agent is possibly carcinogenic for humans
Group 3: The agent is not classifiable as to its carcinogenicity for humans

## 2. Sources

Mannino et al. (Mannino and Orecchio, 2008) sampled and analyzed indoor dusts from 45 environments (bed rooms, living rooms, kitchens, laboratories, offices, market and car). A station within the rural community (Cefalù, Italy) was chosen as sampling area with negligible anthropogenic activities, to establish the source of PAHs. Total PAHs concentrations in dust samples ranged from 36 to 34453 μg $kg^{-1}$ with an average of 5111 μg $kg^{-1}$. The remote and light-urban areas have markedly lower PAHs concentrations than urban/anthropyzed. Taking into account only all domestic environments, the highest total PAHs concentrations was measured in a kitchen while the lower concentrations were measured in the living rooms. PAHs concentrations in indoor dust for smoking household where tobacco is burned **ar**e higher (from 2 times observed in the kitchen to 16 times in the bed rooms) than the others. The results of isomeric ratios suggested that most of the PAHs identified in the residential indoor dust samples were originate from combustion processes, in particular, the highest value was found in the dusts collected in the winner period in a living room where is utilized a fireplace, while in the indoor dusts collected in the petrol pump and in a car PAHs origin from petroleum products. Data relative to five samples of offices and laboratories of a Chemistry Departments which had centralized systems of aeration established that dusts of the studies and laboratory of the same structure have similar relative PAHs distribution, while higher concentrations of total PAHs were observed in the office of Inorganic Chemistry Department. In this case, authors hypnotized that PAHs were transported inside by people. Researchers (Ali et al., 2017) quantified PAHs in dust deposited at several automotive workshops in Jeddah, Saudi Arabia, and assess the health risk to workers through dust

**Table 2**
References relating PAHs sources and their concentrations in several matrices.

| Year | Matrices | Reference | Concentration Range | Unity |
|---|---|---|---|---|
| 2015 | Coffee | Pissinatti et al. (2015) | 1.0-11.3 | μg $Kg^{-1}$ |
| 2015 | Ash of biomass | (Masto et al., 2015) | 0.19-193 | mg $Kg^{-1}$ |
| 2015 | Ash of biomass | Achten et al. (2015) | 13-251 | ng $g^{-1}$ |
| 2015 | Air exposure | C.-C. Wu et al. (2015) | 3-77 | ng $day^{-1}$ |
| 2016 | Smoked cheese | ((Commission regulation EU No 835/2011 & 2011)) | 1.1-176 | μg $Kg^{-1}$ |
| 2016 | Smoked paprika | ((Commission regulation EU No 835/2011 & 2011)) | 5332-18118 | μg $Kg^{-1}$ |
| 2016 | Bread | ((Commission regulation EU No 835/2011 & 2011)) | Traces-3.4 | μg $Kg^{-1}$ |
| 2016 | Pellets ashes | (Santino Orecchio, Amorello et al., 2016) | 0.064-0.90 | mg $Kg^{-1}$ |
| 2016 | Air | Bootdee et al. (2016) | 14-45 | ng $m^{-3}$ |
| 2017 | Particulate | Y.-C. Li et al. (2018) | 753-150 | ng $m^{-3}$ |
| 2017 | Corn grains | de Lima et al. (2017) | 102-127 | μg $Kg^{-1}$ |
| 2017 | Settled dust automobile workshops | Ali et al. (2017) | 7620-30800 | ng $g^{-1}$ |
| 2018 | Chicken | El Husseini et al. (2018) | 1.5-49.9 | μg $Kg^{-1}$ |
| 2018 | Carpet floor dust | Kadi et al. (2018) | 2550-9150 | ng $g^{-1}$ |
| 2018 | Particulate | Ding et al. (2012) | 685-1160 | ng $m^{-3}$ |
| 2018 | Gas phase | Ding et al. (2012) | 18-52 | ng $m^{-3}$ |
| 2018 | MateTea | Tfouni et al. (2018) | 194-1795 | μg $Kg^{-1}$ |
| 2018 | Black tea | Tfouni et al. (2018) | 1.8-186 | μg $Kg^{-1}$ |
| 2018 | White tea | Tfouni et al. (2018) | 24-119 | μg $Kg^{-1}$ |
| 2018 | Green tea | Tfouni et al. (2018) | 3.1-92 | μg $Kg^{-1}$ |
| 2019 | Coffee | (S. Orecchio et al., 2009) | 2.17-1.1 | μg $L^{-1}$ |
| 2019 | Indoor air | Rostami et al. (2019) | 2404-7304 | Ng $m^{-3}$ |
| 2020 | Waters | Dobaradaran et al. (2020) | 3.9-5.7 | μg $L^{-1}$ |
| 2020 | Gas phase | F. Lu et al. (2020) | 36-49 | μg $g^{-1}$ |
| 2020 | Particulate | F. Lu et al. (2020) | 2-72 | μg $g^{-1}$ |
| 2021 | Indoor dust | (Sultan H. Alamri et al., 2021a,b) | 3715-6750 | ng $g^{-1}$ |
| 2021 | Indoor dust | Du et al. (2021) | 21-535 | mg $Kg^{-1}$ |
| 2021 | Particulate | (Balram Ambade and Latif, 2021) | 141-172 | μg $m^{-3}$ |
| 2021 | Bacon | Merlo et al. (2021) | 0.10-1.47 | μg $Kg^{-1}$ |
| 2021 | Indoor air | Organization (2015) | 43-155 | ng $m^{-3}$ |
| 2022 | Asphalt | Fathollahi et al. (2022) | 0.019-4.992 | μg $g^{-1}$ |
| 2022 | Coffee | Jordan-Sinisterra et al. (2022) | 12-68 | μg $Kg^{-1}$ |
| 2022 | Air computer room | Seo et al. (2022) | 39 | ng $m^{-3}$ |
| 2022 | Air computer office | Seo et al. (2022) | 34 | ng $m^{-3}$ |
| 2022 | Server room | Seo et al. (2022) | 50 | ng $m^{-3}$ |
| 2022 | University campus | Z. Wu et al. (2022) | 538-7973 | ng $g^{-1}$ |
| 2024 | River water | R. Li et al. (2024) | 0.055 | μg $L^{-1}$ |
| 2024 | Particulate matter | R. Li et al. (2024) | 3.8 | μg $Kg^{-1}$ |
| 2024 | Urines | S. Li et al. (2024) | 29-83 | ng $mL^{-1}$ |
| 2024 | Particulate | S. Li et al. (2024) | 17-114 | ng $m^{-3}$ |
| 2024 | Air | Odekanle et al. (2024) | 14-45 | ng m-3 |
| 2024 | Dust filter Mosques | Alghamdi et al. (2024) | 2405 | ng $g^{-1}$ |
| 2024 | Black tea | Cutillas et al. (2024) | 9.5–39 | μg $Kg^{-1}$ |
| 2025 | Water | Nordberg et al. (2025) | 4-8 | ng $L^{-1}$ |
| 2025 | Sediment | Nordberg et al. (2025) | 200-5500 | ng $g^{-1}$ |
| 2025 | Smoked pork | Iwona et al. (2025) | 1-53 | μg $Kg^{-1}$ |
| 2025 | E-waste | (Zhang et al., 2025) | 35-69 | mg $Kg^{-1}$ |
| 2025 | Recycled plastic | Martín et al. (2025) | 7-2200 | ng $g^{-1}$ |
| 2025 | Nugget (chicken and fish) | Kamali et al. (2025) | 17-37 | μg $Kg^{-1}$ |
| 2025 | Indoor dust | Anonimed (2025) | 77-99 | μg $Kg^{-1}$ |

**Table 3**
Examples of remediation perspective.

| Remediation methods | Reference |
|---|---|
| By Enzymes produced by bacteria and fungi: laccase, lignin peroxidase, manganese peroxidase | Tesfaye et al. (2025) |
| By Synthetic and biological surfactants | Aryal and Liakopoulou-Kyriakides, (2013a, b) |
| By gas stripping strategy (steam extraction) combined with in situ oxidation-assisted microwave | L. Wu et al. (2023) |
| By a bioaugmented slurry remediation system | F. Wang et al. (2026) |
| By 46 genera of microorganisms: Comamonadaceae, Pseudomonas, Flavobacterium, Xanthomonadales, Alcali genaceae and Bacillus | Liu et al. (2019) |
| By 32 strains of bacteria: Pseudomonas, Actinobacteria, Bacillus and Pseudomonas | Acer et al. (2021) |
| By different biosorbents under different conditions | M. Aryal (2020) |
| By electrochemical remediation | Proietto et al. (2024) |

exposure. The total concentrations of the twelve PAHs ranged between 7620 and 30800 ng $g^{-1}$, in particular, the researchers established that the percentage distributions of PAHs were different in the dust coming from workshops for small and heavy vehicles. Global trade significantly influences PAHs concentrations in environmental matrices (R. Li, J. Zhang and P. Krebs). Some authors (R. Li, Hua, Zhang and Krebs, 2020b) assessed the temporal and spatial variations in PAHs concentrations, loads, and mass fluxes along the Rhine and Elbe rivers based on 20-year data and identified the primary sources using an artificial neural network and a receptor model. Between 1998 and 2017, the average concentration of PAHs in suspended particulate matter in the Elbe River basin decreased from 6573 to 3388 ng $g^{-1}$at a rate of −3.3% per year (Anonimed, 2008; Li et al). In this case, researchers (R. Li et al., 2020a) use several methods to identify the sources of polycyclic aromatic hydrocarbons, such as the positive matrix factorization (PMF) receptor model, the Unmix receptor model, and principal component analysis with multiple linear regression (PCA-MLR). A research (Guo et al., 2024) evaluated the impact of commercial traffic over a 10-year period (2004-2014) on global PAHs contamination and the risk associated with human exposure through inhalation. The data obtained establish that PAHs resulting from trade move mainly from developed to less

**Table 4**
Comparative table for indoor and outdoor sources.

| Category | Source | Main PAHs sources | People health measures | Industrial/Technological measures |
|---|---|---|---|---|
| Domestic heating | Indoor | Pellet stoves<br>Wood stoves | Proper ventilation, reduced exposure time | Efficient chimneys, catalytic afterburners, combustion control sensors |
| Tobacco smoke | Indoor | Incomplete combustion of material (cigarettes paper) | Smoking restriction, ventilation of the environments | Tobacco regulation, public smoking bans |
| Candle emission | Indoor | Paraffin combustion and wick pyrolysis | Avoid prolonged exposure, ventilation of the environments | Use of low-emission waxes (soy/beeswax alternatives) |
| Incense emission | Indoor | Biomass combustion in confined spaces | Limited use, ventilation of the environments, exposure reduction | Low-emission incense formulations |
| Computer emission | Indoor | Heating of some components | Limited use, ventilation of the environments. | |
| Food preparation: Drying | Indoor | High-temperature oil degradation | Dietary moderation. adequate air exchange | Optimized cooking appliances, exhaust hoods |
| Food preparation: Rosting, Barbecue, Grilling | Outdoor | Combustion of fats and proteins | Reduce frequency, avoid overcooking, pre-cooking using other methods (microwave, etc.). | Controlled temperature systems, Use of devices with good fume extraction. |
| Food Preparation: smoking | Indoor | Combustion of food components | Controlled and reduce consumption. | Controlled smoking chambers, low-temp drying systems, use of devices with good fume extraction. |
| Food Preparation: fried | Indoor | Combustion of fats and proteins | Reduce frequency, avoid overcooking, choose oils with a high smoke point. | Optimized cooking appliances, extractor hoods |
| Biomass combustion | Outdoor | Incomplete combustion of organic materials | Exposure monitoring | Regulation of open-pit burning, use of greener energy |
| Mosquitos repellent emission | Outdoor | Burning of coils containing insecticides and other materials | Use of electrical alternatives | Development of low-emission repellents |
| Vehicular Traffic | Outdoor | Incomplete combustion of fossil fuels (diesel engines), lubricant oil residues | Limit exposure to high-traffic areas, | Emissions planning, catalytic converters, transition to electric mobility. |
| Waste treatment | Outdoor | Open waste of organic materials treatment | Avoid exposure near treatment plants, monitor air quality | Advanced incineration systems with emission controls (filters, scrubbers), and waste management regulations. |

developed regions, thus resulting in a 28% increase in lung cancer risk in China, 15% in India, and 11% in Southeast Asia. In contrast, a decrease in risk occurred in Western Europe (63%) and the United States (46%) in 2004.

### 2.1. Tobacco smoke

Tobacco smoking poses a global public health threat, causing around 8 million deaths each year (World Health Organization, 2015). Tobacco smoke is a complex mixture containing over 150 gaseous compounds and more than 2000 different molecules, in particulate matter, including numerous PAHs (Neilson, 1988). The concentrations of many hazardous substances in places where smokers live are much higher than those in the outside air and in non-smokers' homes. Pipe smoke, commonly used in Middle Eastern and Asia, produces PAHs. Some authors quantified the compounds present in the indoor air particulate matter of hookah bars in the city of Ardebil (Rostami et al., 2019). The results showed that the PAHs average concentrations in the bars were 5522 ng $m^{-3}$. Specifically, the concentration values were 5915, 2404 and 7304 ng $m^{-3}$ in bars selling fruit-flavored tobacco, regular tobacco, and both, respectively. One study (Adesina et al., 2021) quantified PAHs concentrations in the air of several public bars in southern Nigeria frequented by smokers. The average PAHs concentrations in the different bars ranged from 2.7 to 9.7 ng $m^{-3}$, while $\sum$16 PAHs concentrations ranged from 43 to 155 ng $m^{-3}$. Cigarette butts contain thousands of chemicals (metals, nicotine, aromatic amines, nitrosamines, PAHs, phenols, benzene, toluene, ethylbenzene and xylene) that can be released after exposure to water, such as during rainfall or flooding (Solomou et al., 2023). The ΣPAHs of butts leachates, quantified from 4 h to 21 days, ranged from 3.9 to 5.7, 3.3–5.5 and 3.0–5.0 μg $L^{-1}$ for deionized, tap, and river waters, respectively (Dobaradaran et al., 2020). In this regard, the toxicity of cigarette butt leachates for various aquatic and terrestrial species have been reported on several occasions. In recent years, electronic cigarettes have emerged as an alternative to smoking cigarettes and tobacco, especially among younger generations (Commission, 2021). In e-cigarettes, tobacco, together with other substances (glycerin, propylene glycol, etc.), is simply heated, avoiding combustion, to produce inhalable fumes. Although, in the literature, articles regarding polycyclic aromatic hydrocarbons in electronic cigarettes are limited, some researchers (Goniewicz et al., 2014; Rawlinson et al., 2017) have highlighted the presence of low traces of PAHs and other potentially toxic compounds in the liquids and aerosols used in electronic cigarettes. In particular, they (Rawlinson et al., 2017) reveal the presence of PAHs with three or fewer aromatic rings in the aerosol produced by e-cigarettes, while those consisting of four or more rings have not been detected. Some researchers (Bjurlin et al., 2021) highlight the presence of carcinogens in the urine of e-cigarette users, most of which are strongly associated with bladder cancer. The long-term implications of chronic urothelial exposure to urinary carcinogens in e-cigarette smokers are unknown and will require long-term study. The authors conclude that, although the malignant potential of e-cigarettes for bladder cancer is currently unknown and likely lower than that of traditional cigarettes, the mere presence of urinary biomarkers strongly associated with carcinogenesis is highly concerning. Although the amounts of hazardous substances emitted by e-cigarettes are lower than those emitted by traditional cigarettes, passive exposure to e-cigarette aerosols is not entirely harmless for people in the same environment as the smoker (Cui et al., 2024).

### 2.2. Biomass combustion

The current greater awareness of environmental protection has led to an increase in the use of biomass (Daniela Thrän and Kay, 2017; Toscano et al., 2013). Solid fuel combustion, especially under oxygen deficiency, produces polycyclic aromatic hydrocarbons (Du et al., 2021), therefore, compounds belonging to this group are significantly produced in processes involving food drying and/or smoking. Mcgrath (McGrath et al., 2003) studied the pyrolysis of cellulose at controlled temperatures (300-650 °C) and concluded that no PAHs are formed for T < 300 °C, while at 400 °C, acenaphthylene, anthracene, fluoranthene, fluorene, phenanthrene, pyrene, chrysene, benz[a]anthracene and benzo[a]pyrene were found in the solid residue. The authors (McGrath et al., 2003) also reported that increasing the combustion temperature from 400 to 650 °C resulted in an increase of the PAHs concentration in the gas phase, with fluorene and phenanthrene predominating in the

temperature range between 600 and 650 °C. PAHs and heavy metal chemical fractions were quantified in biomass ashes (Masto et al., 2015) from four power plants that fired coconut and wood wastes. The total PAHs amount ranged from 0.19 to 12.3 mg $kg^{-1}$, except for wood ash (193 mg $kg^{-1}$). Some researchers (Achten et al., 2015) quantified naphthalene concentrations ranging from 13 to 251 ng $g^{-1}$ in soot produced by burning logs. In contrast, naphthalene concentration was lower in homes using natural gas. This difference can be ascribed to the chemical and physical combustion properties of the fuels. Burning fuel oil and wood results in higher PAHs production due to incomplete combustion and the higher carbon content of these fuels (Hamper, 2006). Some authors (Valenti, 2016) describe the results of the quantification of 15 PAHs, identified by the United States Environmental Protection Agency (US-EPA) as subject to priority monitoring, in addition to perylene and other compounds not listed by the US-EPA in wood pellet ash produced by a stove. The total concentrations of the 17 compounds ranged from 0.064 to 0.90 mg $kg^{-1}$ of dry weight, with an average of 0.31 mg $kg^{-1}$. The lowest concentrations (<0.1 mg $kg^{-1}$) were found in conifer ash samples. Naphthalene was the most copious PAH in all investigated ashes having concentration from 0.1 to 0.87 mg $kg^{-1}$. Fig. 3 shows the total concentrations of PAHs quantified in the ash produced by a stove fueled with wood pellets sold in Italy.

The ash obtained from the combustion of pellets, often grayish in color due to incomplete combustion, can be a harmful material for people and the environment, if not handled with appropriate caution, due to the presence of PAHs. Despite ash is frequently praised by environmentalists and pellet stove manufacturers producers for its use as an agricultural fertilizer, the findings of this research highlight the need to assess its chemical composition (Sören and Brümmer, 2002). In particular, it is necessary to avoid the cultivation of plants intended for human and animal consumption that can bio accumulate PAHs. In a research (Sultan H. Alamri et al., 2021a,b), the concentrations of PAHs in house dust, sampled during the COVID-19 lockdown from various households (n = 40) of Jeddah, Saudi Arabia, were quantified and, the total concentration of PAHs was double compared to that determined in the same environments in periods preceding the epidemic. Several of the compounds found in the samples have carcinogen potency differences of several orders of magnitude. Given that B[a]P is the most hazardous compound, the carcinogenic potency of each analyzed ash sample was determined in terms of its B[a]P equivalent concentration ($B[a]P_{eq}$). To calculate the $B[a]P_{eq}$ for each single compound, the use of its toxic equivalent factor (TEF) is required for the given species relative to a B[a]P carcinogenic potency. In literature, little data on TEFs are available (Nisbet and LaGoy, 1992; Petry et al., 1996). In the dust samples, low molecular weight compounds predominated and influenced the total PAHs, while high molecular weight compounds contributed predominantly to the $B[a]P_{eq}$ profile as Toxic Equivalent (TEQ) However, the long-term non-carcinogenic risk was minimal for both the young and adult populations. The impact of lockdown restrictions on the concentration of 16 PAHs in water and suspended matter in the Elbe River from 2015 to 2021 was assessed (S. L. Li, X. Wang, J. Li, J. Wang, Z. Ma, S. Dong, Z. Li, M. Han, Y. Cao, J., 2024). Results show that annual mean concentrations of PAHs in water and suspended particulate matter were determined at 0.055 μg $L^{-1}$ and 3.8 μg $kg^{-1}$ from 2015 to 2021, respectively. Significant decreases in PAHs in suspended particulate matter (up to −18%) were observed during the three lockdowns in Germany from 2020 to 2021. A study (Du et al., 2021) evaluated PAHs emissions from solid fuel used to cook in four provinces of rural China using different types of stoves and fuels. Concentration variations of more than one order of magnitude were measured for burning different fuel types under different combustion conditions. Burning bean straw produced the highest concentrations of PAHs. Wood-burning stoves with gasifiers, also known as clean stoves, had relatively lower PAHs emissions. Furthermore, the total PAHs, expressed as $B[a]P_{eq}$, of the latter type of stove was much lower than that of the traditional brick stoves. Both the percentage distribution of individual compounds and the different isomeric ratios, commonly used in identifying PAHs sources, varied significantly between honeycomb briquettes and charcoal blocks. A recent study (S. L. Li, X. Wang, J. Li, J. Wang, Z. Ma, S. Dong, Z. Li, M. Han, Y. Cao, J., 2024), carried out at Fenwei Plain, in Northwestern China, quantified PAHs in atmospheric particulate (2.5 μm) emitted by combustion of different fuels used for domestic heating and cooking and hydroxylated metabolites (OH-PAHs) in elders urines. In homes using solid fuels, indoor PAHs concentrations were higher than outdoor ones, while indoor concentrations in homes using liquefied petroleum gas were similar to those found in homes using solid fuels. In homes using biogas, PAHs concentrations were significantly lower (64-82%) than those emitted by solid fuels. Different combustion conditions influenced composition of gaseous PAHs indoors between two sampling sites. The total concentration of the 10 metabolites in urine of elderly residents in homes using different types of fuels showed a trend: coal (83 ng $mL^{-1}$) > wood (79 ng $mL^{-1}$) > LPG (52 ng $mL^{-1}$) > biogas (29 ng $mL^{-1}$), in particular, naphthalene metabolites were the predominant ones (about 90%). Regarding the production of PAHs, the combustion of seven types of firewood (Cashew, Mahogany, Gmelina, Shea, Butter Tallow (White hard), Obeche, Iroko) was studied (Odekanle et al., 2024) using standardized procedures. For this purpose, 16 compounds were quantified in the air, in which chrysene, in all cases, is the one with the highest concentrations. All observed PAHs concentrations exceeded the permitted limits of $1 \times 10^{-6}$ and $1.2 \times 10^{-7}$ mg $m^{-3}$ respectively by the European Union and the World Health Organization. PAHs emissions produced during the burning of cashew wood determine the highest levels of toxicity and mutagenicity, while all samples have the same carcinogenic effect. The authors suggest that long-term exposure should be avoided, especially for people with pathologies (asthma, lung cancer and cardiovascular diseases). The spatiotemporal distribution of PAHs in the sediments of a river on the Loess Plateau (China) was assessed (Zhang et al., 2022). The pollutants originated primarily from coal combustion. Concentrations ranged from 194 to 514 ng $g^{-1}$ and were generally higher in the dry season than in the wet season, due to the dilution effect of high river discharge and heavy rainfall. In this case, PAHs present in forest and grassland soils were transferred to rivers through surface and groundwater runoff during light rainfall, resulting in increased PAH concentrations in river sediments. Conversely, heavy rainfall in the wet season cancels out the spatial variations.

### 2.3. Candle emission

Although the risk of exposure to PAHs is not high, it also occurs when visitors are inside mosques and other places of worship for services. One study (Kadi et al., 2018) evaluated the concentrations of phthalates and PAHs in the settled dust collected from the carpets of several mosques located in different residential districts of Jeddah, which varied in size and age, and were located either within residential blocks or in a mall. Total PAHs ranged from 2550 to 9150 ng $g^{-1}$. For these indoor environments, benzo[a]pyrene equivalent carcinogenic power ($B[a]P_{eq}$) (median 145 ng $g^{-1}$) was calculated. From some decades, aromatherapy has been used to provide psychological relief to people suffering from psychological stress and insomnia. Among these treatments, the use of scented candles shown particular importance caused by a rapidly growing demand for scented candles for use in indoor environments (homes, churches, temples, etc.), consequently, an indoor source of PAHs can be derive from indoor candles emission (Ahn et al., 2015; Anonimed, 2011). Wax candles have been employed since IV-V century BC as a source of light and are in the present day recurrently used for decorative and religious purposes. The emission formed during wax candles burning has been proven to contain Volatile Organic Compounds (VOCs) as acetaldehyde, formaldehyde, acrolein, phenol, benzene, toluene, xylene, aromatic and aliphatic hydrocarbons, etc. The Ames test identified, the candles smoke as mutagenic (Lau et al., 1997; Lee and Wang, 2006). In a work, Orecchio (Anonimed, 2011) found total PAHs concentration emitted by candles in the range from 2.3 to 50 μg

$kg^{-1}$ and averaged 15 μg $kg^{-1}$. Recently, researchers (Francesco Armetta, 2025) quantified PAHs in dust sampled from an ancient Italian church in Castelbuono, Sicily. In two of the analyzed samples, fluoranthene, pyrene, and chrysene were the three most abundant components. Interestingly, the percentage distribution of PAHs in the samples was very similar. Specifically, total PAHs concentrations ranged between 77 and 99 μg $kg^{-1}$.

### 2.4. Incense emission

In Eastern countries, millions of believers are accustomed to burning incense in temples, especially those dedicated to Buddha. The burning of incense and their paper has been found to be a significant source of large amounts of particulate matter, heavy metals and gaseous pollutants, in particular, this practice (Gevao et al., 2007), might be an important source of PAHs to the indoor environment. Incense burning is long, slow and, above all, incomplete, and produces dense and incessant smoke. It has been shown that some temple workers, exposed to incense smoke, increase the potential risk of developing acute irritation symptoms, including nose and throat (Chiang and Liao, 2006). Some researchers (Bootdee et al., 2016) evaluated the concentrations of total PAHs in air, during the Chinese New Year, confirming that they were higher than those recorded during other holidays and during all other days of the year. The total concentrations of PAHs, in the 24 h during the Chinese New Year, other holidays and the normal period were 45, 30 and 14 ng $m^{-3}$, respectively. In another study (Niu et al., 2021), PAHs emitted during incense use, in an emission chamber, were quantified. It has been highlighted that compounds having high molecular weight showed higher correlations with DNA damage and inflammatory events, giving rise to possible significant risks to the alveolar epithelium of the human distal respiratory tract. A study (Alghamdi et al., 2024) quantifies the 16 PAHs recommended by the EPA in dust from mosque air conditioning filters (representative of the air breathed by worshippers). The average total PAHs concentration in mosque dust in Jeddah was 2405 ng $g^{-1}$, suggesting that the dust was heavily polluted by this class of substances.

### 2.5. Mosquitos repellent emission

Mosquito repellent incense is one of the most widely used repellents in millions of indoor environments during the summer season, especially during nighttime sleep and is widely used worldwide. Their combustion releases large amounts of fine particles (diameter $\leq$2.5 μm) and gaseous pollutants which could be sources of acute and chronic health risks (L. Wang et al., 2018), black carbon, and polycyclic aromatic hydrocarbons. The emission rates and emission factors of PAHs in the particulate and gas phase released from smoldering mosquito-repellent incense, ranged from 2.0 to 72 μg $h^{-1}$ and 36 to 49 μg $g^{-1}$, respectively (F. Lu et al., 2020). Some researchers (S. Li et al., 2023) have determined that during the use of mosquito coils, indoor concentrations of total volatile organic compounds and particulate matter (2.5 μm) can increase by 2.3-3.3 times and 1.6-7.4 times, respectively, compared to acceptable standards.

### 2.6. Computer emission

If electronic devices are used for a long time especially in enclosed spaces, the pollutants emitted can affect indoor air quality (Seo et al., 2022). Researchers (Seo et al., 2022) studied the release of PAHs by heating computer components in an oven. In the air of a room where computers were located, the concentration of total PAHs was measured to be 39 ng $m^{-3}$, in a server the concentration was 50 ng $m^{-3}$ and in an office 34 ng $m^{-3}$. In these cases, via inhalation, adults in their offices are exposed to about 1.9 ng TEQ $day^{-1}$ (Seo et al., 2022). Low molecular weight PAHs were mainly detected in the gas phase, while high molecular weight ones were substantially present in particulate matter. The authors conclude that the PAHs concentration in indoor air was influenced by the number and size of computers, their age, indoor heat, ventilation, room size and daily usage time. In any case, indoor concentrations were higher than outdoor ones, which highlights the impact of indoor sources of PAHs. This study confirms the possible presence of PAHs in environments where computers are present, establishing that the risk for operators varies according to many factors. In another case (Z. Wu et al., 2022), together with polybrominated diphenyl ethers, the risk of PAHs present in particulate matter, sampled at the university campus in Xinxiang (China), was assessed for university students. Indoor dust samples were collected from dormitories, classrooms, laboratories and offices. The mean concentration of $\sum$ 16 PAHs was 2060 ng $g^{-1}$ dry weight (dry weight).

### 2.7. Vehicular traffic

During combustion in gasoline engines, approximately 95% of the PAHs present in the fuel are destroyed. Additionally, 50% of the PAHs emitted are formed during the combustion process (Neilson, 1988). Most of the PAHs emitted by diesel engines come from those already present in the fuel that are not broken down during the combustion process. In particular, only about 20% of the PAHs emitted are originated from the pyro synthesis of lubricating oils (Neilson, 1988). Emissions from mobile sources (cars, trucks, agricultural vehicles, etc.) depend not only on the type of fuel, but also on the age, maintenance, engine power, vehicle model, and whether the vehicle's engine has been warmed up or not. An Indian study (Balram Ambade and Latif, 2021) quantifies PAHs in $PM_{2.5}$ airborne particulate matter in three areas of Chota Nagpur Plateau to determine temporal and seasonal variations. The mean PAHs concentrations ranged from 141 to 172 ng $m^{-3}$. From the isomeric ratios, it can be established that PAHs associated with PM were of petrogenic, pyrogenic, coal combustion and vehicular emissions origin. In order to dispose of the large number of end-of-life tires, in recent decades, rubber granules obtained from the aforementioned objects are used in the production of road pavements (Huang et al., 2007). Among the hazardous materials that can be released from tire rubber, in addition to some heavy metals, polycyclic aromatic hydrocarbons, can potentially be emitted from the road surface, causing environmental pollution (Fathollahi et al., 2022). The total PAHs in the asphalt samples were lower than that of rubber granulates and ranged from 0.019 to 5.0 μg $g^{-1}$ depending on the volume of rubber granulates in the asphalt mixture and the type of binder. Recreational boats can have a significant impact on the marine environment (water, sediments and organisms) due to PAHs emissions from their engines. In general, older two-stroke engines are much more polluting than four-stroke engines. Swedish authors (Nordberg et al., 2025) evaluate PAHs concentrations in surface sediments and water produced by recreational vessels in two Swedish coastal marine areas (a relatively pristine fjord and a busy port area). Total PAHs concentrations in water and sediments were 4–8 ng $L^{-1}$ and 200–5500 ng $g^{-1}$ respectively.

Researchers (J. Zhang et al., 2019) evaluated PAHs concentrations in four particle size fractions of road particulate matter using data processing methods. In the aforementioned matrix, total PAHs concentrations ranged from 0.45 to 2.03 μg $g^{-1}$. The researchers established that concentrations increase with decreasing size fraction.

### 2.8. Food preparation: Drying

The emission of PAHs during open burning of plants (wood, straw, leaves, etc.) is mainly caused by low combustion efficiency and is linked to the emission of particulate matter. Drying of many agricultural products (cereals, seeds, etc.) is an often-unavoidable process to reduce water content to avoid or limit post-harvest biological activities to ensure shelf life and preserve the organoleptic and chemical-physical qualities of the product, in this case, PAHs can accumulate in soybeans, corn, rice, cocoa, etc. during this process. The formation of low and high molecular weight PAHs typically occurs at temperatures

between 400 and 800 °C, with the maximum production of four compounds (B[a]A, Chr, BbF and B[a]P) at temperatures between 500 and 600 °C (De Lima et al., 2017). In the case of corn grains, submitted to drying with firewood, seven compounds were detected: fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene and chrysene were detected. Average PAHs levels, determined in corn samples and in the control sample submitted to different drying temperatures using firewood and direct fire ranged from 102 to 127 μg $kg^{-1}$ while in the control the ΣPAHs was 5.9 μg $kg^{-1}$. Researchers (Silva et al., 2018) used a validated analytical method for the determination of PAHs in vegetable oils obtained from different types of seeds (*Cocos nucifera* L. *Carthamus tinctorius* L., *Oenothera biennis* L. and *Linum usitatissimum* L.). Chrysene was the compound with the highest concentration, followed by B[a]A, while B[b]F and B[a]P were generally lower than 2.0 μg $kg^{-1}$. The oil with the highest concentration of total PAHs was that of primrose (*Oenothera biennis*), mainly due to Chr. The presence of PAHs in raw materials (vegetable oils, beans, corn, and dairy products, such as powdered milk) used in the preparation of baby foods often determines their contamination. Petrarca (Petrarca and Godoy, 2018) quantified 12 PAHs in 32 ready-to-eat infant formulas. In all samples, PAHs, even if present, were lower than the limit established by Regulation (EU) No. 835/2011 of the European Union for infant formulas (1 μg $kg^{-1}$ for B[a]P and 1 μg $kg^{-1}$ for the sum of B[a]P, Chr, B[a]A and B[b]F) (EU - European Union, 2011).

### 2.9. Food preparation: Barbecue, Grilling

In some regions of the United States, cooking processes in restaurants result in emissions of particulate matter that often exceed legal limits for $PM_{2.5}$. Some research (Buonanno et al., 2009) has reported that emissions from meat cooking activities contribute significantly to ambient concentrations of fine $PM_{2.5}$. According to several authors (Farhadian et al., 2012), the formation of PAHs depends on the type of food, in particular on its composition. The preparation of foods prior to cooking, for example, marinating (a technique to improve the flavor and tenderness of meat) can reduce the formation of some carcinogenic compounds, such as heterocyclic aromatic amine. Some researchers (Y.-C. Li et al., 2018) quantified 19 PAHs associated with fraction 2.5 μm of atmospheric particulate matter emitted during five different cooking methods. Total PAHs concentrations in the air from cooking activities were 4.2 to 36 times higher than those of the corresponding background environments. The highest concentrations of total PAHs were observed preparing food by frying in the canteen (783 ng $m^{-3}$), followed by roasting meat (420 ng $m^{-3}$), roasting fish (210 ng $m^{-3}$), boiling in the canteen (202 ng $m^{-3}$) and boiling in the canteen (150 ng $m^{-3}$). It can be assumed that the above differences are due to the method as well as the fat content in the raw materials and the consumption of oil. PAHs with four to six rings accounted for 87.5% of the total PAHs. The isomeric ratios were similar between the two grilling methods and the other three traditional Chinese cooking methods, respectively, demonstrating the predominance of cooking methods in PAHs emissions. A significantly high benzo[b]fluoranthene/benzo[k]fluoranthene (B[b]F/B[k]F) ratio (8.3) was observed in street boiling, attributed to the use of charcoal as fuel. Both the Flu/(Flu + Py) and [B[a]An/(B[a]An + Chr)] ratios were higher for oil-based cooking than those for water-based cooking. Also, two ratios of indeno[1,2,3-cd]pyrene/(indeno[1,2,3-cd]pyrene + benzo[g,h,i]perylene) [Ip/(Ip + B[g,h,i]Pe) and benzo[(a]pyrene/(benzo[a]pyrene + benzo[g,h,i]perylene) [B[a]P/(B[a]P + BPE)] were higher for two grilling methods than for the three traditional Chinese grilling methods. Some researchers (Fasano et al., 2016) evaluate the concentrations of 10 PAHs in some typical dishes and Spanish cheeses (Pan de Cea, Pimentón de la Vera, Chorizo, San Simón da Costa, Idiazábal and Humus). Bread was baked in a standard wooden oven while for the preparation of Pimenton the fruits were dried with smoke produced by oak wood for 10-15 days. San Simón da Costa is a cheese smoked using wood, the birch, from a tree typical of the production area. In bread samples, the total concentration of 10 PAHs ranged from traces to 6.5 μg $kg^{-1}$, with a mean of 3.4 μg $kg^{-1}$. The analytes were found in the bread crust. In this case, none of the analyzed samples exceeded the legal limits proposed by the Official Journal of the European Union for processed cereal-based foods (Commission regulation (EU) No 835/2011 & 2011). A study (El Husseini, Makkouk, Rabaa, Al Omar and Jaber, 2018) evaluates the exposure of the Lebanese population to four PAHs assumed by the consumption of one of the typical foods, in particular chicken grilled using charcoal. The total concentrations of four PAHs ranged from 1.5 to 50 μg $kg^{-1}$ and, in almost 40% of the grilled chicken samples analyzed, the concentrations were higher than the EU Commission limit of 12 μg $kg^{-1}$ (El Husseini et al., 2018). In many countries, the frequent custom of organizing outdoor barbecues provides an opportunity to bring family and friends together. Moreover, in this case, in addition to ingestion of food and drinks, PAHs can enter the body through skin absorption. To quantify this, food preparation by barbecue was taken into consideration by a researcher (Ding et al., 2012). In this case, nine hydroxyl (OH)-PAHs were analyzed in urine samples from participants and 16 PAHs in air, food and cotton clothing samples at different distances from the grill. It is known that during barbecues, participants are exposed to emissions that contain PAHs. Some authors (C.-C. Wu, Bao, Lian-Jun, Guo, Ying, Li, Shao-Meng, Zeng, Eddy Y, 2015) confirmed that bystanders would be exposed to significant amounts of PAHs through skin absorption and inhalation even if they did not consume the grilled food. The concentrations of PAHs in the gas phase and in the particulate matter were 1160 and 52 ng $m^{-3}$ at 2 m distance and 685 and 18 ng $m^{-3}$ at 10 m distance, respectively. It is clearly seen that the concentrations in the two phases decrease with distance from the barbecue. These results are in good agreement with previous data obtained in Urumqi, China (C.-C. Wu, Bao, Lian-Jun, Guo, Ying, Li, Shao-Meng, Zeng, Eddy Y, 2015). In this latter case, exposure via inhalation and skin contact by adult consumers spending 1 h per day near a charcoal grill vendor for a normal meal (lunch or dinner) amounted to an amount of PAHs, expressed as $B[a]P_{eq}$, ranging from 3.0 to 77 ng per day (inhalation: 2.8-27 ng $day^{-1}$; skin contact: 0.2-50 ng $day^{-1}$) which can be compared to those (22-220 ng $day^{-1}$) resulting from the consumption of (50-150 g) charcoal grilled meat. Traditional smoking of meat, fish and other foods, often carried out in an oxygen-deficient manner, is one of the most popular preservation methods based on the dehydration obtained by heat and the antibacterial action of smoke components (phenols, organic acids and their esters) generated by the use of specific woods (Kubiak and Polak-Śliwińska, 2015). This process also gives smoked foods particular and appreciated organoleptic characteristics (Racovita et al., 2020; Racovita et al., 2021). On the other hand, during smoking, unwanted chemical substances are formed, which are absorbed by food, such as polycyclic aromatic hydrocarbons, heterocyclic amines, nitrosamines, formaldehyde and others (Racovita et al., 2021). Some authors (Iwona et al., 2025) have quantified 16 PAHs in both traditionally and industrially smoked pork (loin, neck, belly) with different fat content. Using traditional method, 9.7 μg $kg^{-1}$ of PAHs were quantified in pork loin, while the highest concentration was found in the skin (15 μg $kg^{-1}$), followed by the outside (6.5 μg $kg^{-1}$), inside (1.7 μg $kg^{-1}$) and center (0.10 μg $kg^{-1}$). In industrially smoked lion, the median concentration was 0.61 μg $kg^{-1}$ in the skin, while no PAHs were detected inside the food. In traditionally smoked neck, the median concentration was 28 μg $kg^{-1}$, the adipose tissue contained about 20% less PAHs than the skin, but about 30% more than the marble and 60% more than the lean tissue. In traditionally smoked bacon, 53 μg $Kg^{-1}$of PAHs were quantified, the adipose tissue contained 10% less than the skin and 20% more than the lean layer. Industrially smoked bacon contained concentrations lower than 1 μg $kg^{-1}$.

### 2.10. Food preparation: Smoking

During the smoking process of foods, PAHs, can be formed due to

incomplete combustion or thermal decomposition of organic compounds of the wood. Molecular fragments and free radicals produced by this process react to form first light PAHs and then heavy PAHs, which are accumulated in the fatty parts of foods due to their high hydrophobicity. The smoking process gives rise to the formation of PAHs, in this regard, some researchers (Merlo et al., 2021) quantified the concentrations of B[a]P in bacon samples subjected to different smoking methods (open fireplace, partially closed, closed, with high and low ventilation) at variable times and temperatures (from 65 °C to 75 °C and 30-60 min). The sum of three compounds was between 0.10 and 1.5 μg $kg^{-1}$, while B[a]P was below the detection limits in most of the samples (<0.10 μg $kg^{-1}$). In some countries, meats are often smoked using rudimentary methods. Some researchers (De Souza et al., 2022) have determined B[a]P concentrations in traditionally smoked (4 h at 60-70 °C) and liquid smoked alligators, finding concentrations of 0.07 μg $kg^{-1}$ and 0.05 μg $kg^{-1}$, respectively.

### 2.11. Food preparation: Roasting

Drying and roasting are fundamental production phases in coffee and tea production, as it allows the development of color, aroma and flavor. On the other hand, this process can lead to the formation of unwanted compounds, such as polycyclic aromatic hydrocarbons (L. Culotta, 2009; Guizellini et al., 2025). Coffee toasting includes an intense thermal process, which can be applied by direct (flame-toasting, coal-grilling or gas oven toasting) or indirect (electric oven-toasting) way. Although commercial coffee toasting is performed around 250 °C in an electric oven, higher temperatures could be easily reached by consumers at home. As a result of intense thermal processes, partial carbonizations could take place in coffee. Coffee beans, which usually contain about 10–17% fat, are especially vulnerable to PAHs contamination (Cutillas et al., 2024). Formation of phenanthrene, anthracene and benz[a] anthracene in coffee beans was observed at temperatures above 220 °C, whereas formation of pyrene and chrysene required 260 °C. Benzo[g,h,i] perylene low concentrations were also noted in dark roasting under 260 °C, with simultaneous partial degradation of three-cycle PAHs, suggesting that transformation of low molecular PAHs to high molecular PAHs occurs as the roasting degree is increased. The PAHs transfer to the infusion was quite moderate (<35%), with a slightly lower extractability for dark-roasted coffee as compared to light-roasted coffee (Houessou et al., 2007). Authors (Pissinatti et al., 2015) in the commercial samples of roasted coffee quantified 10 PAHs by isotope dilution gas chromatography-mass spectrometry. The concentrations ranged from 1.00 to 11 μg $kg^{-1}$. Several studies have been aimed at quantifying PAHs in both powder and beverage samples. Researchers (Dos Santos et al., 2019a,b; Jordan-Sinisterra et al., 2022; Pissinatti et al., 2015) quantified PAHs in commercially available coffee samples, prepared to simulate typical filter coffee consumption. B[a]P was not detectable in the samples analyzed by Dos Santos et al. (Dos Santos et al., 2019a,b), on the contrary, other authors (Pissinatti et al., 2015) detected concentrations between 0.40 and 0.51 μg $kg^{-1}$. Appreciable concentrations of other high molecular weight PAHs, including B[b]F and B[a]A, suggest that coffee consumption could be a source of this class of compounds towards consumers (Jordan-Sinisterra et al., 2022). Tfouni (Tfouni et al., 2018) quantified PAHs in yerba mate samples, finding the presence of high concentrations (194 to 1795 μg $kg^{-1}$) of B[a]A, Chr, B[b]F and B[a]P in the infusions, attributing them to the roasting of the herbs and to the smoke generated during the combustion of the wood for the repeated roasting phases, while in black, white and green tea they were decidedly lower, respectively (1.8-186 μg $kg^{-1}$), (24-119 μg $kg^{-1}$) and (3.1-92 μg $kg^{-1}$) (Tfouni et al., 2018). Despite the presence of PAHs in the tea leaves, only traces of the PAHs were found in the beverage. Benzo[k] fluoranthene, benzo[b]fluoranthene, pyrene, acenaphthylene and acenaphthene are the most abundant PAHs found in 27 samples of the beverages obtained using roasted and ground coffee (100% Arabica or blend) from Brazilian local supermarkets. The total concentration of 16 PAHs ranged from 2.2 to 1.1 μg $L^{-1}$ (Rosimeire Resende dos Santos et al., 2019). A simple, sensible, and high-throughput method was developed by several researchers (Jordan-Sinisterra et al., 2022) to quantify 8 PAHs in brewed coffee samples. In this case, the total PAHs amount ranged from 12 to 68 μg $kg^{-1}$. The combustion of pine wood during the drying stage of tea leaves can lead to a high PAHs content in black tea. The black tea production consists of withering, rolling, fermentation and drying. The contamination of the tea leaves increases dramatically after the drying stage (Cutillas et al., 2024). Unlike black tea, green tea does not undergo fermentation. Real sample analysis of black tea from various brands and origins revealed the presence of several PAHs with concentrations ranging 9.5–39 μg $kg^{-1}$, some exceeding the maximum residue levels set by the European Union (Cutillas et al., 2024). Beer is the most consumed alcoholic beverage in the world, currently, is obtained from the alcoholic fermentation of must prepared with malt (often roasted or partially roasted), barley or wheat (or mixtures thereof) and water, flavored with hops. As already mentioned for other foods, drying and roasting barley, in addition to providing compounds that give the drink its organoleptic characteristics, are sources of unwanted substances such as PAHs. Twenty-six beer samples, including ten Pilsen and sixteen dark (ten roasted malt and six caramel), were analyzed for derivative PAHs (dos Santos et al., 2021). Benzo[b]fluoranthene was found in all samples, while, only 9-fluorenone and 9-nitroanthracene were found among the PAHs derivatives (dos Santos et al., 2021). For the production of oils intended for human consumption, starting from different types of oilseeds, different industrial extraction processes are required, including chemical extraction, solvent extraction and aqueous enzymatic extraction. As in other cases, at each production stage, the formation of PAHs can occur, due to the relatively high temperatures used for preheating and pressing the seeds, as well as the use of contaminated solvents and environmental factors that influence the raw materials (Guizellini et al., 2025; Favaro et al., 2022).

### 2.12. Food preparation: Fried

Some authors (Kamali et al., 2025) quantified PAHs in 24 samples of nuggets (chicken and fish), cooked using 3 different methods and two types of edible oils. The PAHs concentrations found in the analyzed samples ranged between 17 and 37 μg $kg^{-1}$. Total concentrations were higher in fish nuggets than in chicken nuggets. Microwave cooking was found to be preferable to deep-frying. The authors state that the presence of PAHs in the foods studied is due to the cooking processes and the types of raw materials used. PAHs are usually formed when foods are cooked at high temperatures for a long time, especially in the presence of fats and proteins. Furthermore, if the ingredients are contaminated with PAHs, these compounds may also be present in the final food (Sharifiarab et al., 2023).

### 2.13. Waste treatment

In recent years, before disposal of waste in landfill, attempts are being made to reuse or recycle it in relation to European Commission directives (EC Directive on end-of-life vehicles and EC Directive on landfill) (Commission, 2000) that concern the management of used tires. One of the methods for recycling used tires is pyrolysis. In a study, the formation behavior and distribution of PAHs in three-phases were investigated from waste tires under pyrolysis conditions. PAHs were mainly concentrated in the pyrolysis oil (95-99%), so care should be taken to control these compounds when using pyrolysis oil. In some cases, tires, after being reduced to granules or powder, are reused in flooring for playgrounds and sports stadiums, as shock-absorbing mats for schools and stables, as blocks or tiles for patio and swimming pool flooring and as roofing material. Granulated rubber has also been used in the production of synthetic grass for football pitches. Recently, this last application has raised numerous questions about the potential health risks deriving from the hazardous substances present in recycled

rubber (Skoczyńska et al., 2021). In materials taken from football pitches, rubber tiles and car tires, authors (Skoczyńska et al., 2021) quantified several methylated PAHs, together with the 16 EPA PAHs and B[e]P, B[j]F and perylene. The results showed that PAHs concentrations in several samples were below the European safety limits for mixtures, but above the safety limits for consumer products. In Dutch doormats, PAHs concentrations exceeded the EU limits, while in a Spanish doormat the limits were exceeded by up to several hundred times. In these objects containing recycled tires, methylated PAHs predominate.

The motherboards of personal computers and the printed circuit boards present in the peripheral components of computers and in any electronic device, contain a large number substances that arouse interest and concern, since many metals could be recovered instead they are generally abandoned, furthermore, the presence of toxic substances, even at low concentrations, such as heavy metals (mercury, cadmium, lead, etc.) and flame retardants of the plastic materials (pentabromophenol, polybrominated diphenyl ethers, tetra bromo bisphenol A, etc.), create damage to the environment and living beings. Motherboards are made up of approximately 40% metal, 30% plastic materials, and the rest ceramic. In order to limit the constant increase of electronic waste volumes and ensure their appropriate treatment, currently, mechanical-physical processes are widely used for the recovery of precious metals present in the above-mentioned e-waste. After the separation of precious metals, the non-metallic residue can be transported to landfills or subjected to incineration. E-waste dismantling activities result in the formation of PAHs. High concentrations of 16 priority PAHs in different environmental matrices sampled in the vicinity of e-waste dismantling and recycling areas have been quantified, suggesting potential health threats to occupationally exposed workers (S.-y. Lu et al., 2016). PAHs formation is mainly caused by the pyrolysis of various plastic polymers contained in e-waste, direct heating of scrap printed circuit boards for reusable component recycling and open-pit burning of plastic insulated wires to extract precious metals. Here, the authors (S.-y. Lu et al., 2016) determined urinary concentrations of 10 target OH-PAHs (1-Nap, 2-Nap, 2-Fluo, 3-Fluo, 1-Phen, 2-Phen, 3-Phen, 4-Phen, 9-Phen, and 1-Pyr), 8-hydroxy-2′-deoxyguanosine and malondialdehyde in residents and workers at the e-waste dismantling site and two reference sites. The authors established that e-waste dismantling workers and people living near recycling sites were shown to have significantly elevated risks of developing cancer and cardiovascular diseases. Pyrolysis is an efficient and clean way to reduce the emissions of toxic pollutants (such as halogenated dioxins/furans) and recover value-added products (Zhang et al., 2025). During pyrolysis, organic fractions decompose into gas and oil, which serve as alternative energy sources or chemical raw materials for various industrial sectors. However, the pyrolysis process often cannot be used because PAHs are produced, which remain in the ash and can be leached into the environment. The formation of PAHs in this process depends on numerous factors (the type of raw material, the grain size, the pyrolysis temperature, the heating rate, the residence time of the volatiles, the atmosphere and the properties of the catalysts). Also in accordance with the Community Directives (Union, 2018), plastic recycling is an activity that results in the production of material that is reprocessed into products for their original or alternative uses. However, due to the possible presence of hazardous substances, it is almost impossible to use recycled plastic from post-consumer sources for more complex applications such as food packaging. Some authors (Martín et al., 2025) have quantified the content of the 16 priority PAHs in 25 samples of different types (PET, HDPE, LDPE and PP) of recycled plastic from different companies. The lowest concentrations were found in PET samples (7–120 ng $g^{-1}$). In contrast, the highest concentrations were quantified in LDPE (2210 ng $g^{-1}$), in the PP/PE/EPDM blend (1500 ng $g^{-1}$) and finally in another HDPE sample (1020 ng $g^{-1}$).

### 2.14. Low temperature processes

Very little data in literature is available on PAHs emissions during use in children's products. Some authors (Liang et al., 2026) have recently detected the presence of naphthalene and many other substances (more than 200) in plastic toys. Given the unpleasant odors emitted by many plastic toys, especially recycled plastic, researchers (Even et al., 2021) used GC-MS to study VOCs emissions from several samples of plastic costume masks. The presence of naphthalene was also identified in a sample. Polycyclic aromatic hydrocarbon emissions and contamination of environmental matrices can also occur at low temperatures, regardless of combustion processes. Creosote, is a liquid used, especially in the past, for wood preservation (Ahn et al., 2015; Gallego et al., 2008) in hot and humid environments for their fungicidal and algaecide properties. It is obtained by fractional distillation of crude coal tar produced by high-temperature carbonization of bituminous coal (Agency, 1999). Its composition consists of a mixture of hundreds of compounds with variable composition (qualitatively and quantitatively), most of which are volatile organic compounds and PAHs. The European Union has imposed regulations on the marketing and use of creosote and wood treated by it (Council Directive 1994; Ikarashi et al., 2005). The Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE, 1999) has highlighted that the cancer risk associated with creosote is greater than previously thought and exceeds the limits allowed by current registration regulations. Based on this evidence, the European Council (Commission of the European Communities, 2001) has approved a new Directive (2001/90/EC), which establishes that creosote may not contain B[a]P in concentrations exceeding 50 ppm. By European Parliament and Council, creosote is classified as carcinogenic (Carc. 1B, H350) (Council, 2008). Based on the valuation as a biocidal active substance, classification with Reprotoxicity 1B (H360F), Repr. 2 (H361d), Skin Irritation 2 (H315), Skin Sensitivity 1 (H317) and the hazard for the aquatic environment (Aquatic Acute 1 (H400) and Aquatic Chronic 1 (H410)) was suggested (Commission, 2010). This profile of hazardous properties makes the implementation of comprehensive risk management measures indispensable. One concern with creosote-impregnated products is the long-term release of a wide variety of hazardous compounds into environmental matrices. In most treatment processes, wood is impregnated with creosote under pressure in such a way as to penetrate deep into the wood. Although large quantities of wood products are impregnated every year around the world, there are few recent studies on the volatilization of PAHs from creosote-treated wood, often detectable by nose without the use of sophisticated equipment. In the field of civil engineering, creosote has been used to impregnate railroad ties, railroad switches, utility poles, telephone poles, orchard poles, fish farm poles, bridges, wharf structural members and wooden decks for domestic use, garden fences, door and window lintels for country homes and fireplace mantelpieces. Since the invention of steam trains by several engineers (including Richard Trevithick and George Stephenson) in the early 19th century, railway sleepers have been a distinctive and indispensable element of railway tracks. The recycling of disused railway sleepers as exterior wood for use in gardens has recently become popular in many countries. The probability of coming into contact with creosote components is high even unknowingly for general public. Although railway sleepers have been exposed to air and water in different atmospheric conditions for several decades, the presence of high concentrations of PAHs as residues in this type of wood has been reported (Ikarashi et al., 2005). Often, consumers unknowingly purchase and come into contact with this type of wood, which may pose health risks. The typical smell that is often perceived in railway stations near the platforms, especially in the older and secondary ones, is that of creosote. Researchers (Ikarashi et al., 2005) quantified PAHs in used and new railroad ties, foundation piles, and wooden pickets obtained and supplied by the Japan Wood Preservers Industry Association. New or used railway sleepers and foundation piles contained significant amounts of B[a]P (58–749 μg $g^{-1}$) and benz[a]anthracene (250–1282 μg $g^{-1}$). The combustion of creosote impregnated wood such as redundant railways sleepers' could constitute an enhanced sources of PAHs (Neilson, 1988).

In several environmental matrices, under anaerobic conditions, some PAHs can be originated from biogenic precursors such as pigments and steroids (Bergamasco et al., 2014). According to Tissier (Boudou et al., 1985), a perylene contribution exceeding 10% in sediments indicates a diagenetic origin, formed biologically under anaerobic conditions. In a review, Wilcke (2000) cites examples from literature that report these compounds in soil, flowers and termite nests. Thiele and Brummer (Thiele, 2002) reported that biological formation of 3, 4, 5, and 6-rings PAHs was observed after incubation of fresh plant material and soil mixed with fresh plant material under reducing conditions. Perylene quinones (pigments found in several organisms) are suspected to be degraded to perylene by anaerobic microbial metabolism (74,75).

## 3. Mitigation and remediation perspectives

### 3.1. Mitigations

The European Commission recently approved a new limit that will come into force on April 22, 2026, regarding the presence of PAHs in clay targets intended for sport shooters. Specifically, according to Regulation (2025)/660/EU, PAHs cannot be present in clay targets at concentrations exceeding 50 mg $kg^{-1}$, equivalent to 0.005% by weight. EU estimates indicate that the production and use of these targets generates a release into the environment of at least 270 tons of PAHs per year. For centuries, home heating with wood-burning fireplaces has been used primarily by populations living in forested rural areas because wood is relatively cheap compared to other energy sources, which are often not readily available in such areas. However, burning wood, even in domestic fireplaces, emits PAHs and many other undesirable substances. Some authors (Butschbach, Hammer, Kohler, Potreck and Trautmann, 2009) have conducted tests on two different types of wood-burning fireplaces, demonstrating that the use of sensors for online and in-situ monitoring of combustion temperature, the equivalent $CO_2$ concentration of incompletely combusted gaseous components in the flue gases, and other parameters allows for the introduction of a highly efficient control algorithm for managing primary and secondary air flows. Furthermore, combustion efficiency improves if a catalyst is used in the post-combustion chamber or at another point in the flue where the temperature is below 1000 °C. Undoubtedly, these measures, in addition to improving combustion processes, reduce emissions of unwanted substances. Starting January 1, 2022, the European Ecodesign Directive (Union, 2015) introduced stringent requirements for wood-burning and pellet stoves. This regulation aims to increase the energy efficiency of heating appliances and reduce emissions of pollutants improving air quality. Although the external appearance of new wood- and coal-burning stoves and fireplaces has not changed over time, more efficient fireplaces and stoves are now commercially available. They consume less fuel than in recent decades, while emitting smaller quantities of unwanted compounds, including PAHs. These innovations are linked to an innovative system: dual combustion. During the normal initial combustion phase in a coal- or wood-burning fireplace or stove, residues in the form of particles and gases are formed. If no additional action is taken, these residues are expelled through the flue. In dual combustion models, some of the incompletely oxidized substances, such as PAHs, are oxidized during the initial combustion by injecting pre-heated air, which causes the gases and particles to ignite. Many types of paprika, such as *Pimentón de La Vera*, are produced using a smoking process that imparts unique organoleptic characteristics to the finished product, highly prized by consumers. However, this drying process also increases concentrations of polycyclic aromatic hydrocarbons to worrying concentrations. Researchers (Velázquez et al., 2022) compared two new drying processes designed to limit PAHs content with the traditional one. The authors concluded that the moisture content of fresh peppers is a crucial factor in reducing smoking times and, consequently, PAHs contamination. Furthermore, keeping drying temperatures as low as possible ensures good color stability of the paprika and limits the production of PAHs. Confinement of the fire to a closed chamber, with smoke exposure controlled by a fan, improved quality and color stability compared to traditional drying with direct exposure to smoke and it reduced PAHs contamination compared to the use of barrel ovens with four nozzles, where indirect smoking occurred. In the context of indoor activities, particularly those involving meal preparation, some researchers (S.-Y. Wu et al., 2025) have studied the relationship between food composition, cooking methods, and emissions of unwanted pollutants, suggesting solutions to limit the formation of the latter. They have determined that during frying, plant-based proteins produce lower emissions of PAHs and fine particulate matter than those produced by animal-based proteins. Furthermore, they have determined that baking and air frying produce substantially lower emissions than traditional frying. Clearly, the findings of this research have direct implications for suggesting healthier and more environmentally friendly cooking practices.

### 3.2. Remediation perspectives

Since the Industrial Revolution, PAHs pollution of environmental and food matrices has increased dramatically due to the intensification of combustion, coking, and petrochemical activities (Anonimed, 2010; Zhou et al., 2024). Concentrations of these pollutants in areas near industrial zones have been shown to far exceed the standard limit. The presence of PAHs, primarily due to human activities, in environmental and food matrices must be monitored by the scientific community and regulatory authorities because it causes undesirable effects on organisms. The degradation of PAHs by enzymes produced by bacteria and fungi has been proposed by various researchers as an effective technology for these contaminants. To this end, laccase, lignin peroxidase, manganese peroxidase, and versatile peroxidases have been studied (Tesfaye et al., 2025). The authors describe the fundamental catalytic mechanisms that regulate PAHs biodegradation and the parameters for biodegradation to occur. The authors conclude that although some ligninolytic enzymes producing strains are efficient in the complete biodegradation of certain types of PAHs, further research is needed to explore the complete biodegradation of PAHs with more complex molecular structures by genetically modified strains. The biodegradation of PAHs could be an environmentally friendly and cost-effective remediation technique for removing these compounds from the environment, but its potential is severely limited due to their low bioavailability. A researcher (M. Aryal, 2021) argue that the use of surfactants can increase the bioavailability of PAHs in aqueous solutions by simultaneously reducing both surface and interfacial tension. In conclusion, the authors discuss the impact of synthetic and biological surfactants on PAHs biodegradation and the possible mechanism of bacterial degradation in micellar solutions. Therefore, research is needed to develop environmentally sustainable remediation technologies to mitigate the potential risks of PAHs and promote the safe reuse of contaminated soil. Some authors (L. Wu et al., 2023) proposed a gas stripping strategy (steam extraction) combined with in situ oxidation-assisted microwave remediation. They used a multifunctional $MnO_2$/$KHCO_2$@BC modifier to enhance the (difficult) desorption of PAHs from deep pores and interlayers of soil particles. They reached the maximum removal efficiency of pyrene from contaminated soil of about 98%, using the following conditions: 600 s remediation time, 700 W microwave power, 5% addition of $MnO_2$/$KHCO_3$@BC and 2 M acid concentration. Remediation of contaminated soil using bio augmented sludge is a sustainable technique for PAH-contaminated soils. From a practical standpoint, this technology has been improved by some authors (F. Wang et al., 2026) using a combination of bio augmentation, optimization of conditions, and the addition of nitrogen sources and surfactants. Researchers evaluated the effects of adding peptone or Tween-80 on PAH removal by the NS4 agent in the system. Adding Tween-80 increased removal efficiency with or without the addition of peptone. Researchers (Aryal and Liakopoulou-Kyriakides, 2013a,b) have evaluated the use of surfactants

associated with the Arthrobacter strain for the biodegradation of phenanthrene and pyrene in aqueous solutions. In this case, microorganism growth increased as the concentration of Tween 20 and Tween 80 increased above the critical micelle concentration. Triton X-100 and dodecyl sulfate completely inhibited bacterial growth. For microbial remediation of estuarine environments, where PAHs pollution is often more pronounced, it is important to identify indigenous bacteria that possess efficient degradation capabilities and are adapted to the aforementioned environmental conditions. Researchers (Liu et al., 2019) studied 46 genera of PAH-degrading microorganisms in the Yangtze River estuary, including Comamonadaceae, Pseudomonas, Flavobacterium, Xanthomonadales, Alcali genaceae and Bacillus. Acer et al. (Acer et al., 2021) isolated 15 novel aerobic PAHs degraders from Mahoning riparian sediments in Lowellville, Ohio, USA, mainly related to Stenotrophomonas, Pseudomonas, Brucella, and Achromobacter. In this study, they sampled 32 strains of PAH-degrading bacteria (Pseudomonas, Actinobacteria, Bacillus and Proteobacteria, Klebsiella, Bacillus, and Pseudomonas) isolated from estuarine sediments. Biosorption could be another method for the remediation of PAHs in aqueous matrices, although it presents limitations due to their poor aqueous solubility. In a review (M. Aryal, 2020), Aryal compare the results obtained using different biosorbents under different conditions. They also report kinetic, isothermal, and thermodynamic studies of biosorption and the mechanisms of biosorption and desorption.

A promising approach for sediment remediation could be electrochemical remediation, as it is a cost-effective, effective, and non-invasive in situ technology. Electrochemical remediation is commonly studied in the presence of relatively high electric fields ($E \geq 1$ V cm$^{-1}$) and using expensive process fluids in a three-compartment cell, with the goal of desorbing and transporting contaminants in the process fluids (hazardous secondary effluent). Italian researchers (Proietto et al., 2024) treated electrochemically marine sediments contaminated with PAHs and heavy metals, inserting electrodes directly into the sediments at low E values ($\leq$0.25 V cm$^{-1}$) for 96 h. They concluded that PAHs can be degraded directly in situ, reducing energy consumption. Initially, studies were performed on clayey marine sediments sampled in the coast of Capo Granitola (Trapani, Italy) spiked with five PAHs congeners (5 PAHs), Hg, and As. A total PAHs removal efficiency of 57% was achieved after 96 h of treatment at 0.05 V cm$^{-1}$. Subsequently, they studied real polluted marine sediments from the Augusta Bay (Syracuse) and the Bagnoli-Coroglio Bay (Naples) in southern Italy, obtaining a fairly satisfactory PAHs removal efficiency, whereas this approach, under the adopted conditions, is not suitable for Hg and As remediation.

## 4. Conclusions

This review examines articles on most of the known sources of polycyclic aromatic hydrocarbons published in scientific journals over the past 10 years identifying smoking, food preparation (especially grilling and smoking), biomass combustion, and vehicle emissions as dominant daily sources of PAH exposure. Some habits and activities, even if they don't directly produce PAHs, may be related to their transport, diffusion, and bioaccumulation. In this regard, plastic waste, such as that resulting from the use of disposable tableware, if not properly sorted and recycled, undergoes a series of processes in the environment, even under natural conditions (mechanical, UV radiation, biological degradation, thermal oxidation, hydrolysis, etc.), resulting in the formation of secondary micro plastics. Recent studies have shown that many pollutants, especially nonpolar and lipophilic ones such as PAHs, can be transferred from seawater to marine and aquatic biota, such as plankton, fish, mussels, and whales, via micro plastics. This process alters the fate, distribution, and toxicity of PAHs to aquatic organisms. Addressing this contamination requires a dual approach: public awareness to reduce emissions at the source, and the application of robust remediation strategies, such as enhanced microbial biodegradation and biosorption, to clean up existing environmental pollution. This review represents a relevant updated in the scenarios of polycyclic aromatic hydrocarbons from common daily activities, enriching and supporting the recent literature by relevant global datasets. The data presented are certainly of interest both to researchers working in the scientific field and to designers and engineers (chemical, construction, industrial) who could draw inspiration from them in the design of new production processes and industrial plants. It is also recommended for *Earth Condominiums* to understand the activities to which they are exposed daily and the products they consume. A critical reading of the aforementioned sources should encourage everyone to potentially change their lifestyles.

## CRediT authorship contribution statement

**Silvia Orecchio:** Writing – original draft, Data curation, Conceptualization. **Diana Amorello:** Writing – original draft, Validation. **Giuseppe Arrabito:** Writing – original draft, Validation. **Salvatore Barreca:** Writing – original draft, Validation.

## Declaration of competing interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property. We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript. We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author.

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## Data availability

No data was used for the research described in the article.

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