Journal of Anatolian Environmental and Animal Sciences
(*Anadolu Çevre ve Hayvancılık Bilimleri Dergisi*)
DOI: https://doi.org/10.35229/jaes.1558892

JAES
Year: 9, No: 4, 2024 (703-710)
AÇEH
Yıl: 9, Sayı: 4, 2024 (703-710)

ARAŞTIRMA MAKALESİ RESEARCH PAPER

The Association of Diesel Vehicle Emissions And Diesel Passenger Car Preferences with Cancer and Chronic Respiratory Airway Disease Deaths in Türkiye: An Ecological Study

Ömür GÜNGÖR[1]* Özge ÖZATA GÜNGÖR[2]

[1]*Health Sciences University, Adana City Training and Research Hospital, Department of Pulmonary Diseases, Division of Occupational Diseases Yüreğir, Adana. Türkiye*

[2]*Gazi Mustafa Kemal Occupational and Environmental Diseases Hospital, Department of Ear Nose Throat Diseases, Yenimahalle,Ankara, Türkiye*

Received: *01.10.2024* ***Accepted:*** *09.12.2024* ***Published:*** *31.12.2024*

How to cite: **Güngör, Ö. & Özata Güngör, Ö. (2024).** The Association of Diesel Vehicle Emissions And Diesel Passenger Car Preferences with Cancer and Chronic Respiratory Airway Disease Deaths in Türkiye: An Ecological Study. *J. Anatolian Env. and Anim. Sciences*, ***9***(4), 703-710. https://doi.org/10.35229/jaes.1558892

Atıf yapmak için: **Güngör, Ö. & Özata Güngör, Ö. (2024).** Türkiye'de Dizel Araç Emisyonları ve Dizel Binek Araç Tercihlerinin Kanser ve Kronik Solunum Yolu Hastalığı Ölümleriyle İlişkisi: Ekolojik Bir Çalışma. *Anadolu Çev. ve Hay. Dergisi*, ***9***(4), 703-710. https://doi.org/10.35229/jaes.1558892

*: https://orcid.org/0000-0002-6524-8088
: https://orcid.org/0000-0002-7315-7741

***Corresponding author's:**
Ömür GÜNGÖR
Health Sciences University, Adana City Training and Research Hospital, Department of Pulmonary Diseases, Division of Occupational Diseases, Yüreğir, Adana. Türkiye
✉: omurgungor70@hotmail.com

Abstract: The first aim of this study was to investigate the relationship of increased emissions from diesel vehicles with the ratios of chronic respiratory disease and cancer deaths. Secondly, this study aims to investigate the types of cancer deaths associated with the increase in diesel passenger cars. The fuel types and engine types of cars in traffic since 2004 were obtained from national statistics data (TurkStat) and Automotive Distributors and Mobility Association data. Chronic respiratory disease and cancer death rates were calculated using the TurkStat data. Time-lag correlation analysis was examined to evaluate the relationship between the increase in the number of diesel vehicles and deaths from diseases (5-year lag). The increase in diesel vehicles correlated with deaths from colon (r: 0.81), pancreas (r: 0.83), rectum (r: 0.79), bladder (r: 0.83), and skin (r: 0.59) cancers in males. For females, there was a correlation between the increase in diesel vehicles and deaths from lung and larynx (r: 0.73), colon (r: 0.66), pancreas (r: 0.85), bladder (r: 0.66), breast (r: 0.85), uterus (r: 0.91), and ovarian (r: 0.81) cancers. The increase in diesel car preference was associated with deaths from lung and larynx (r: 0.57), colon (r: 0.59), and bladder (r: 0.63) cancers in females. The outcomes underscore the potential public health impact of diesel vehicle emissions and the need for regulatory policies to mitigate these harmful effects. Promoting cleaner alternatives can be a supportive step in the fight against cancer.

Keywords: Air pollution, cancer, diesel exposure, environment.

Türkiye'de Dizel Araç Emisyonları ve Dizel Binek Araç Tercihlerinin Kanser ve Kronik Solunum Yolu Hastalığı Ölümleriyle İlişkisi: Ekolojik Bir Çalışma

***Sorumlu yazar:**
Ömür GÜNGÖR
Sağlık Bilimleri Üniversitesi, Adana Şehir Eğitim ve Araştırma Hastanesi, Göğüs Hastalıkları Anabilim Dalı, Meslek Hastalıkları Bölümü, Yüreğir, Adana. Türkiye
✉: omurgungor70@hotmail.com

Öz: Ulaştırma sektöründeki artan taleplere yanıt olarak dizel araçların kullanımı son 20 yılda hızla artmıştır. Dizel motorlar çeşitli avantajları nedeniyle binek otomobiller için popüler bir tercih haline gelmiştir. Bu çalışmanın ilk amacı dizel araçlardan kaynaklanan artan emisyonların kronik solunum yolu hastalığı ve kanser ölüm hızlarıyla ilişkisini araştırmaktır. İkinci olarak, bu çalışma dizel binek otomobillerdeki artışla ilişkili kanser ölüm türlerini araştırmayı amaçlamaktadır. Trafikteki araçların yakıt türleri ve motor türleri 2004 yılını kapsayacak şekilde Türkiye İstatistik Kurumu (TÜİK) verilerinden ve Otomotiv Distribütörleri ve Mobilite Derneği verilerinden elde edilmiştir. Kronik solunum yolu hastalığı ve kanser ölüm oranları TÜİK verileri kullanılarak hesaplanmıştır. Dizel araç sayısındaki artış ile hastalıklardan kaynaklanan ölümler arasındaki ilişkiyi değerlendirmek için time-lag korelasyon analizi yapılmıştır. Time-lag semi-partial korelasyon testi kullanılarak dizel araç tercihiyle ilişkili kanser türlerinden kaynaklanan ölümler analiz edilmiştir. Dizel araçlardaki artış erkeklerde kolon (r: 0.81), pankreas (r: 0.83), rektum (r: 0.79), mesane (r: 0.83) ve cilt (r: 0.59) kanserlerinden kaynaklanan ölümlerle ilişkiliydi. Kadınlarda dizel araçlardaki artış ile akciğer ve gırtlak (r: 0.73), kolon (r: 0.66), pankreas (r: 0.85), mesane (r: 0.66), meme (r: 0.85), uterus (r: 0.91) ve yumurtalık (r: 0.81) kanserlerinden kaynaklanan ölümler arasında bir ilişki vardı. Dizel araç tercihindeki artış kadınlarda akciğer ve gırtlak (r: 0.57), kolon (r: 0.59) ve mesane (r: 0.63) kanserlerinden kaynaklanan ölümlerle ilişkiliydi. Sonuçlar, dizel araç emisyonlarının potansiyel halk sağlığı etkisini ve bu zararlı etkileri azaltmak için düzenleyici politikalara olan ihtiyacı vurgulamaktadır. Daha temiz alternatifleri teşvik etmek, kansere karşı mücadelede destekleyici bir adım olabilir.

Anahtar kelimeler: Çevre, dizel maruziyeti, hava kirliliği, kanser.

INTRODUCTION

Diesel vehicles are widely used due to their energy efficiency, durability, and low running costs (Drizik et al., 2020). In the last two decades, significant technological advances have been made to diesel engines used in automobiles. For this reason, diesel cars have become popular given that they are more advantageous

than gasoline cars, especially in terms of fuel economy. Although economical, diesel engine exhaust is a source that has significant effects on air pollution (Karthikeyan et al., 2024). Diesel exhaust causes global warming and climate change by releasing greenhouse gases that are harmful to ecosystems, such as hydrocarbons, nitrogen oxides, sulfur dioxide, and particulate matter (Candela et al., 2024; Li et al., 2023). Nitrogen oxide reduces air quality and has adverse effects on the respiratory tract. Additionally, nitrogen oxide emissions contribute to ozone formation (Pirhardi et al., 2024). The sulfur content in diesel fuel causes sulfur dioxide emissions that contributes to acid rain and damages the respiratory system (saini et al., 2024). Particulate matter in diesel exhaust, especially fine particles, cause respiratory tract irritation and reduced respiratory capacity (Font et al., 2024; Sabanov et al., 2024). Particularly, polycyclic aromatic hydrocarbons from diesel exhaust have been implicated in cancer cases (Li et al., 2024; Tian et al., 2024). Diesel emissions have been designated as a group 1 carcinogen by the International Agency for Research on Cancer (IARC), according to data regarding lung cancer (IARC, 2011). Although the type of cancer most researched in relation to diesel exhaust exposure is lung cancer, existing research studies have shown associations and risk to many organ cancers, such as bladder, pancreatic, and colon cancers (Koutros et al., 2020; Fang et al., 2011; Sassano et al., 2024). Almost all studies on diesel exhaust exposure and its relationship with cancer have investigated occupational effects and have been conducted on the working population (Koutros et al., 2023). Despite posing significant health risks for workers, diesel exhaust fumes from traffic represent a major public health concern for the entire society due to their contribution to air pollution. The aim of this study was to examine the effect of increased diesel engine emissions from road transportation on deaths from chronic respiratory airway disease and cancer. Furthermore, we aimed to determine the types of cancers correlated with the increasing adoption of cars with diesel engines within the last 20 years.

MATERIAL AND METHOD

Study design and population: This ecological study examined the effect of increased diesel emissions from road transportation on public health in Türkiye. The total number of road vehicles in traffic since 2004, including heavy-duty diesel vehicles, motorcycles, special-purpose vehicles, and road machinery was obtained from the Turkish Statistical Institute (TurkStat) website (TurkStat, 2023a). The number of automobiles and light commercial vehicles and the distribution of cars registered as traffic according to fuel type were obtained using Automotive Distributors and Mobility Association data (ODMD, 2024). The outcome variables were mortality rates, obtained from the TurkStat website (TurkStat, 2022). The death rate was calculated by dividing the number of people who died from a type of cancer or respiratory airway disease by the population in the same year, separately for males and females per 100,000 people. Our study encompassed the entire society, without making any distinctions between age groups and examined the all-country data without any geographical limitations, such as a city or region. The first impact variable that may affect deaths was all diesel vehicles among the road transportation vehicles. The relationship between the proportion of the total number of diesel vehicles among all road transportation vehicles and death rates was examined. Because the effects of traffic-related air pollution on chronic diseases and cancers might appear after an extended period, the calculations were calculated with a 5-year shift. Since the majority of studies on diesel exposure use a 5-year period, the same time lag was used in our study (Möhner et al., 2017). There is no legal recommendation regarding diesel vehicle sales in Türkiye and diesel automobile sales continue. With the development of diesel engine technology, diesel car sales have increased significantly in Türkiye since 2004 (figure 1). The second impact variable was the proportion of diesel cars in the emission pool of road transport. Vehicles with diesel-engines are an option for people in the consumer automobile market. However, for heavy-duty vehicles, there is no current alternative and diesel-fueled engines are used due to their energy efficiency (Lloyd & Cackette, 2001). Assuming that diesel cars are an option while non-automobile diesel vehicles are a necessity, we examined the effect of diesel cars on death rates by controlling the effect of non-car diesel road transportation vehicles. We attempted to examine the relationship between death rates and the increasing number of diesel cars using a statistical method because the two independent variables had the same effect. As the data analyzed in this study were downloaded from open public websites, ethical approval and informed consent were not required. The research did not involve human cases.

Statistical analysis: In this study, the Jamovi Project Program (computer software, version 2.3.2022) was used for all analyses. The mortality rates were the dependent variable of the study and were calculated using the program. In model 1, the independent variable was the ratio of all diesel vehicles on road transportation. The total percentage of diesel vehicles in the emission pool was calculated by dividing the total number of diesel vehicles by the total number of road transportation vehicles within that year. The relationship between diesel vehicles and death rates was examined using the time-lag correlation

test (lag of 5 years). In Model 2, the independent variable is the proportion of passenger cars among all road vehicles. For model 2, the non-automobile diesel vehicle ratio was used as a control variable. With model 2, the cancer types that were associated with the proportion of diesel vehicles in model 1 were examined, and the effect of non-automobile diesel vehicles was removed from the dependent variable using the time-lag semi-partial correlation (in Jamovi, R package) test (Kim, 2015). A p-value of <0.05 was considered statistically significant, and the results were evaluated with a 95% confidence interval.

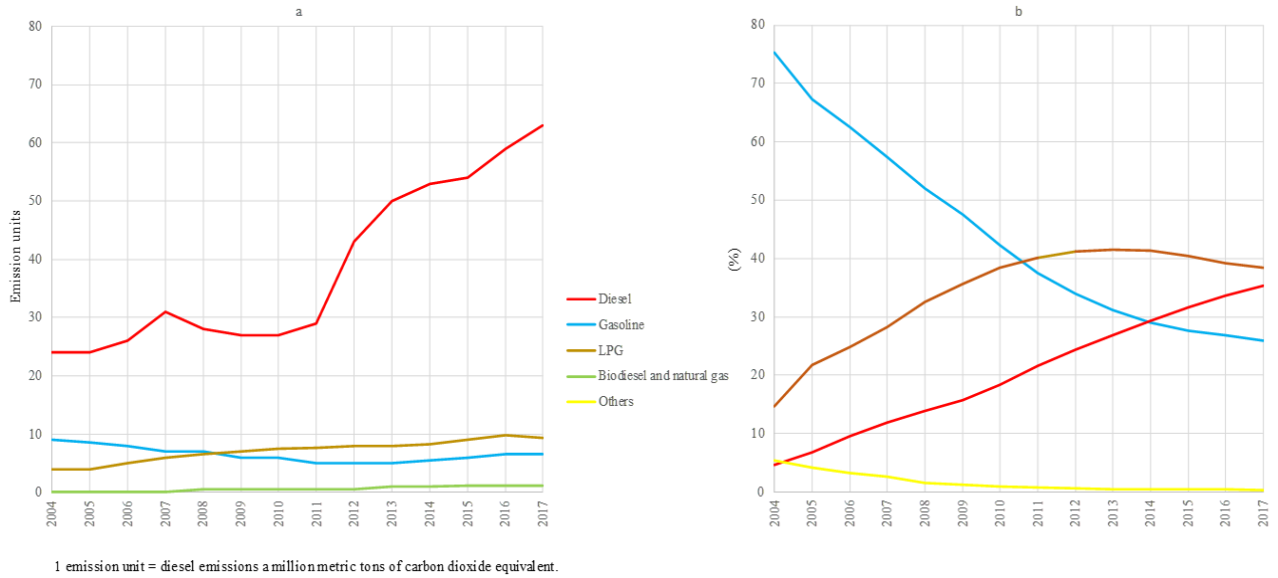

Figure 1. (a) Emission values of diesel vehicles in road transport, (b) diesel car rates among all cars by year.

RESULTS

According to the obtained data, the emission values of the total diesel vehicles in road transport showed a significant increase (TurkStat, 2023b). Concurrently, there was a notable rise in the preference for diesel cars (figure 1). In males (Table 1), the increase in the rate of diesel vehicles in traffic was mostly associated with deaths from pancreas and bladder cancers (r: 0.83, p<0.05). Also, a positive correlation was observed between death rates from colon and rectal cancers (r: 0.81 and r: 0.79, respectively; p<0.05). Skin cancer death rates were moderately related (r: 0.59, p<0.05). In females, death rates from uterine cancers were highly associated with an increase in diesel emissions (r: 0.91, p<0.05). Among females (Table 2), breast and ovarian cancers were also strongly positively correlated (r: 0.85 and r: 0.81, respectively; p<0.05). The association of pancreatic deaths was similar in males (r: 0.85, p<0.05). The increasing rate of diesel vehicles in traffic was associated with a moderate increase in deaths from colon and bladder tumors in females (r: 0.66, p<0.05). Unlike males, death rates from lung and larynx cancers in females were also correlated (r: 0.73, p<0.05). The relationship between the increased rate of diesel vehicles and rectal and anal cancers in males was not observed in females (r: 0.12, p>0.05). No correlation was observed between the increase in diesel vehicles and deaths from chronic respiratory tract diseases in both males and females (r: 0.23 and r: 0.35, respectively; p>0.05). Using model 2, the effect of non-car diesel vehicles was removed from the variables found to be significant in model 1 (Table 3). We observed that the increase in diesel passenger car preferences has no relationship with the types of cancer in males. It was associated with colon, bladder, and lung and larynx cancers in females (r: 0.59, r: 0.63, and r: 0.57, respectively).

Table 1. The relationship between the increasing use of diesel vehicles in road transportation and death rates in males.

	Model 1		
Region of malignant neoplasm	r	(95% CI)	p-value
All malignant neoplasms	0.24	(–0.34–0.68)	0.41
Lip, oral cavity, and pharynx	0.13	(–0.43–0.62)	0.66
Lung and larynx	0.07	(–0.48–0.58)	0.82
Esophagus	–0.09	(–0.59–0.47)	0.77
Stomach	–0.06	(–0.57–0.49)	0.84
Colon	0.81	(0.50–0.94)	0.001*
Liver and intrahepatic biliary ductus	0.08	(–0.47–0.58)	0.80
Pancreas	0.83	(0.52–0.94)	0.001*
Rectum and anus	0.79	(0.45–0.93)	0.001*
Kidney	0.19	(–0.38–0.66)	0.51
Bladder	0.83	(0.54–0.95)	0.001*
Lymphatic/haematopoietic tissue	0.03	(–0.51–0.55)	0.91
Skin	0.59	(0.08–0.85)	0.03*
Prostate	0.13	(–0.43–0.62)	0.66
Chronic respiratory airway diseases	0.23	(–0.34–0.68)	0.42

*p-value <0.05 is significant.
r: correlation coefficient.
Model 1: time-lag correlation test (lower-upper).
Chronic respiratory airway diseases: asthma, chronic obstructive pulmonary disease, and bronchiectasis.

Table 2. The relationship between the increasing use of diesel vehicles in road transportation and death rates in females.

Model 1			
Region of malignant neoplasm	r	(95% CI)	p-value
All malignant neoplasms	0.53	(0.83–0.00)	0.05
Lip, oral cavity, and pharynx	0.13	(–0.43–0.62)	0.65
Lung and larynx	0.73	(0.33–0.91)	0.003*
Esophagus	–0.22	(–0.67–0.35)	0.44
Stomach	–0.38	(–0.76–0.19)	0.19
Colon	0.66	(0.21–0.88)	0.01*
Liver and intrahepatic biliary ductus	0.09	(–0.46–0.59)	0.76
Pancreas	0.85	(0.58–0.95)	0.001*
Rectum and anus	0.12	(–0.44–0.61)	0.69
Kidney	–0.31	(–0.72–0.26)	0.28
Bladder	0.66	(–0.20–0.88)	0.01*
Lymphatic/haematopoietic tissue	0.01	(–0.52–0.54)	0.97
Skin	0.39	(–0.17–0.77)	0.16
Breast	0.85	(0.57–0.95)	0.001*
Uterus	0.91	(0.74–0.97)	0.001*
Ovarian cancer	0.81	(0.48–0.94)	0.001*
Cervix	0.10	(–0.45–0.60)	0.73
Chronic respiratory airway diseases	0.35	(–0.22–0.74)	0.22

***p-value <0.05 is significant.**
r: correlation coefficient.
Model 1: time-lag correlation test (lower-upper)
Chronic respiratory airway diseases: asthma, chronic obstructive pulmonary disease, and bronchiectasis.

Table 3. The relationship between the increase in diesel passenger car preferences in road transportation and cancer deaths.

Model 2		
Region of malignant neoplasm	r	p-value
Males		
Pancreas	0.49	0.09
Colon	0.49	0.09
Rectum and anus	0.17	0.58
Bladder	0.43	0.15
Skin	0.30	0.31
Females		
Lung and larynx	**0.57**	**0.04***
Pancreas	0.48	0.10
Colon	**0.59**	**0.03***
Bladder	**0.63**	**0.02***
Breast	0.34	0.25
Uterus	0.41	0.17
Ovarian cancer	0.39	0.19

***p-value <0.05 is significant.**
r: correlation coefficient.
Model 2: values found to be significant in model 1 were controlled for non-automobile diesel vehicles using the semi-partial correlation test (note, variation from the control variables is only removed from the variables in the first columns)

DISCUSSION

The transportation industry is the largest source of greenhouse gas emissions (Andrés & Padilla, 2018). Road transportation accounts for 95% of transportation sector emissions (Seo, 2016). Numerous nations and areas are concentrating their efforts on lowering exhaust emissions and transitioning to more ecologically friendly modes of transportation. Solutions such as better exhaust control systems, alternative energy sources, and vehicles with reduced emissions are part of these initiatives. In our study, there was a correlation between the rise in new diesel car purchases and female deaths from lung, larynx, bladder, and colon cancers. Although maintenance costs and prices are high, those who want to buy a new car prefer diesel engine automobiles due to lower fuel consumption costs per kilometer. However, due to increased concerns about diesel engines causing environmental pollution and the harmful effects of diesel degradation product gases on human health, the United Kingdom government has planned to ban diesel vehicles by 2040, and car emissions in Europe are planned to be zero by 2035 (Shammut et al., 2019; European Commission, 2024a). There has been an increase in diesel passenger car emissions in European Union (EU) member countries after 2010, with the addition of changes in transportation fuel taxation (Ptak et al., 2024). Within the EU, passenger automobiles account for around 16% and light commercial vehicles for 3% of total emissions of carbon dioxide (CO_2), which is the primary greenhouse gas responsible for climate change (European Commission, 2024a). More than 25% of road transport-related greenhouse gas emissions and more than 6% of all greenhouse gas emissions are caused by heavy-duty vehicles in the EU. These emissions are still rising despite recent improvements in fuel efficiency, mostly due to an increase in road freight traffic (European Commission, 2024b).

The lungs are the most affected organ by air pollution, and many airborne chemicals spread throughout the body via the respiratory system. Consequently, most studies on emissions exposure have focused on lung cancer. The relationship between diesel emission exposure and lung cancer is supported by evidence from research on workers in highly exposed industries, such as mining and trucking (Romero et al., 2024). A cohort study evaluating eight non-metallic mining operations in the USA of which 96% of the participants were male found that standardized mortality rates for lung cancer were elevated compared with state-based mortality rates (1.26, 95% CI 1.09–1.44) due to diesel gas exposure. Although exposure was associated with an increased risk of death from esophageal cancer (1.83, 95% CI 1.16–2.75), it was not associated with an increased risk of death from bladder cancer (Attfield et al., 2012). The results of our study show that while the increase in diesel emissions is associated with lung cancer and laryngeal cancer deaths in females, there was no association in males. Although there are studies supporting the relationship between diesel exposure and lung cancer in males, there are also studies indicating no relationship that supports our findings (Richiardi et al., 2006; Boffetta et al., 1990; Soll-Johanning et al., 2003). Richiardi et al. 2006, found that the odds ratio (OR) for any exposure to diesel exhaust was 1.04 (95% CI 0.79–1.37) in a case-control study covering a sizable population in Italy. There was no correlation found between exposure duration, likelihood, or intensity. Boffeta et al. (1990), found the crude OR to be 1.31 (95% CI 1.09–1.57) in their population study of employees with possible exposure, but this value decreased to 0.95 (95% CI 0.78–1.16) when correcting for smoking and other confounding factors. A Danish study showed that the risk of lung cancer decreased with exposure (0.97 per year added, 95% CI 0.96–0.99). Also, no relationship was found between diesel exposure and bladder cancer (Soll-Johanning et al., 2003). However, due

to insufficient evidence of a dose-response relationship in such studies, there is still controversy regarding the IARC's decision to link diesel exposure with lung cancer (Romero et al., 2024; Möhner et al., 2017). Our research uses an ecological methodology to investigate environmental exposure. We think that the cumulative dose is higher for individuals exposed to diesel exhaust in their workplace environments. Considering that the majority of workers working in work environments exposed to diesel fumes are male, most of the existing studies have focused predominantly on male workers (Romero et al., 2024; Möhner et al., 2017). Biological responses to environmental toxicants can differ between males and females. Females' hormonal cycles and fat tissue ratios can affect the way some toxic substances accumulate and are metabolized in the body. Females generally have a lower bodyweight than males, which could mean a higher dose for females when exposed to the same amount of toxic substances (Vahter & Gochfeld, 2007). Furthermore, many of these studies compare exposed individuals to unexposed populations. In contrast to these approaches, our study uses a regression model to analyze the data. At the same time, our dataset includes the larynx in addition to the lungs among the anatomical regions considered for exposure assessment. In a hospital-based case-control study conducted by Muscat et al. (1995), the relationship between laryngeal cancer and exposure to diesel emissions was investigated among male patients. The OR for laryngeal cancer associated with diesel exposed occupations, compared with a control group, was 0.96 (95% CI 0.5–1.8). The findings indicated no significant association between occupational exposure to diesel fumes and the risk of developing laryngeal cancer.

There is limited evidence that diesel exhaust exposure is associated with bladder cancer. In our study, deaths from bladder tumors were associated with an increase in diesel exposure in both males and females (in model 1). In a study conducted in America and Spain, a significant relationship was found between diesel exhaust exposure and bladder cancer when all registered subtypes were evaluated according to stage and records (Koutros et al., 2020). Petersen et al. (2010), found that in the study of male bus drivers, although the significance was disrupted when adjusted for smoking, the standardized incidence rates of cancer increased the risks of bladder cancer (OR 1.6, 95% CI 1.2–2.0) and lung cancer (OR 1.2, 95% CI 1.0–1.4) compared with unexposed men. In our study, we observed a correlation between the increase in the number of diesel vehicles and deaths from colon cancer in both males and females. It is possible that the increase in diesel car preference might have affected the number of colon cancer deaths in females by increasing the cumulative amount of diesel emissions in circulation. The risk of colon cancer has been observed in various occupations and industrial sectors where there is exposure to diesel engine emissions (Fang et al., 2011). A study conducted in Scandinavian countries concluded that diesel exposure was associated with a small increase in the risk of rectal cancer (OR 1.05, 95% CI 1.02–1.08) (Talibov et al., 2019). A recent meta-analysis showed that exposure to diesel exhaust fumes might increase the risk of pancreatic cancer (OR 1.11, 95% CI 1.02–1.22). In liver cancer, although it suggests a positive association for the pooled estimates, it did not reach significance (OR 1.41, 95% CI 1.09–1.82). In particular, no significance was observed in studies published after 2000. As such, the results of the study supported our outcomes (Sassano et al., 2024). Our findings indicate a correlation between the rise in the number of diesel vehicles and deaths from breast, ovarian, and uterine tumors. We hypothesize that the estrogenic effects of polycyclic aromatic hydrocarbons contained in diesel exhaust could contribute to the development of these tumor types (Zhang et al., 2017). Contrary to our study, Pedersen et al. did not observe any significant association between exposure to diesel exhaust and breast cancer. In addition, exposure to diesel exhaust was found to moderately increase the risk of estrogen-negative tumors in individuals under the age of 50 years (OR: 1.26, 95% CI 1.09–1.46) (Pedersen et al., 2012). In another study, Pedersen et al. (2023), reported an increased risk of breast cancer in daughters of women occupationally exposed to certain agents, such as diesel exhaust, benzopyrene, and bitumen fumes. Regarding maternal exposures, the study observed an association between perinatal exposure to diesel exhaust and breast cancer in girls (OR 1.13, 95% CI 1.01–1.27). Guo et al. (2004), suggested a significant exposure–response relationship between diesel exhaust exposure and ovarian cancer. However, they observed no effect of this exposure on other types of cancer. In our study, we identified a moderate association between diesel exposure and skin cancer, exclusively in males; however, studies in the literature have not found any evidence of a relationship between skin cancer and occupational diesel exposure (D'Agostini et al., 2024).

In our results, dieselization was not correlated with deaths from chronic respiratory diseases. A recent cohort study of mine workers examining the association between deaths from chronic obstructive pulmonary disease (COPD) and diesel exposure assessed the risk under an intervention that removed elemental carbon and respirable dust. The results show a negative association between cumulative exposures and COPD mortality (OR 0.85, 95% CI 0.55–1.06 and OR 0.93, 95% CI 0.56–1.31) (Neophytou et al., 2024). Chronic air pollutants, such as traffic emissions, have progressive effects on airway diseases, and diesel exhaust gas causes respiratory

symptoms (Aghapou et al., 2022; Peyre-Costa et al., 2024). McCreanor et al. (2007), showed that exposure to real-life roadside diesel traffic in people with asthma led to a significant but largely asymptomatic decrease in lung function. The reason for the lack of a significant relationship in our study might be that additional diseases and co-morbidities frequently accompany respiratory diseases. Additional diseases, such as infectious diseases, and co-morbidities, such as cardiovascular diseases, might have been entered in the records as the main cause of death.

A strength of our study is that it examines 20 years of records of the entire country's population. In environmental analyses, the level of exposure was significantly lower compared with occupational exposures. However, unlike the working population, which is exposed only during work hours, there is continuous exposure in the general population. There was no healthy worker effect and no exposure to additional occupational carcinogens. Unlike studies examining a defined workplace, this is an ecological study focusing on environmental interactions. Although there are many studies on males exposed to diesel emissions, sufficient research has not been conducted on the female population. One of the limitations of our study is that the number of vehicles is known, but the distance traveled by these vehicles is not accounted for. Considering that diesel vehicles have low costs per kilometer, it is possible that they would be used for long distance journeys. Due to technological changes, the release of some harmful substances could have been prevented and emission values might have decreased. Although our study focuses on diesel vehicles in road transport, it is important to note that there are other sources of air pollution. Emissions from the aviation, railway, and maritime transportation sectors causes air pollution. However, it has negligible proportions compared to land transportation. The second limitation of our study is that confounding factors, primarily industrial air pollution and cigarette smoke, were not adequately addressed. Industrial pollution is a public health problem that varies regionally and has a wide variety of ingredients. Our study is registry-based and limited to the data that can be obtained. For this reason, regional analysis and detailed examination of age groups could not be conducted. The effect of smoking could not be eliminated due to reasons such as the lack of population-level smoking data and the unusability of lagged smoking prevalence in the analysis even if data were available. This was the most important limitation of the study. However, it may only affect the types of cancer associated with smoking. In conclusion, the damage caused by diesel exhaust gas to the environment and, therefore, to public health cannot be ignored. Many studies have focused on workers' health and exposure. The cumulative increase in exhaust gases can affect the entire society. To counter this problem, restrictions on diesel vehicles should be increased and accelerated. Future research should continue to explore the environmental associations and the mechanisms by which diesel emissions affect health outcomes.

ACKNOWLEDGEMENTS

We thank all vehicle manufacturers who contribute to technologies that reduce the environmental impact of vehicles and environmentally friendly technologies to move towards a zero-emission future.

Funding: No funding was used for this study.

Availability of data: The datasets used and/or analysed during the current study a vailable from the corresponding author on reasonable request.

Declarations Ethics approval and consent to participate: As the data analyzed in this study were downloaded from open public websites, ethical approval and informed consent were not required. The research did not involve human cases.

Consent for publication: Not applicable.

Competing interests: The authors declare no competing interests.

REFERENCES

Aghapour, M., Ubags, N.D., Bruder, D., Hiemstra, P.S., Sidhaye, V. & Rezaee, F. (2022). Role of air pollutants in airway epithelial barrier dysfunction in asthma and COPD. *Eur Respir Rev*, ***23*,** (163), 210112. PMID: 35321933, PMCID: PMC9128841. DOI: 10.1183/16000617.0112-2021

Andrés, L. & Padilla, E. (2018). Driving factors of GHG emissions in the EU transport activity. *Transp Policy*, ***61***, 60-74.

Attfield, M.D., Schleiff, P.L., Lubin, J.H., Blair, A., Stewart, P.A. & Vermeulen, R. (2012). The diesel exhaust in miners study: a cohort mortality study with emphasis on lung cancer. *Journal of the National Cancer Institute*, ***104***(11), 869-883. DOI: 10.1093/jnci/djs035

Boffetta, P., Harris, R.E. & Wynder, E.L. (1990). Case-control study on occupational exposure to diesel exhaust and lung cancer risk. *American Journal Of Industrial Medicine*, ***17***(5), 577-591. DOI: 10.1002/ajim.4700170504

Candela, A., Sandrini, G., Gadola, M., Chindamo, D. & Magri, P. (2024). Lightweighting in the automotive industry as a measure for energy efficiency: Review of the main materials and methods. *Heliyon*, ***10***(8), DOI: 10.1016/j.heliyon.2024.e29728

D'Agostini, M., Collatuzzo, G., Teglia, F. & Boffetta, P. (2024). Risk of skin cancer in workers exposed to diesel exhaust: a systematic review and meta-analysis of cohort studies. *La Med del Lav*, ***115***(2), DOI: 10.23749/mdl.v1

Drizik, E., Corbett, S., Zheng, Y., Vermeulen, R., Dai, Y. & Hu, W. (2020). Transcriptomic changes in the nasal epithelium associated with diesel engine exhaust exposure. *Environ Int*, ***137***, 105506; DOI: 10.1016/j.envint.2020.105506

European Commission. (2024a). CO_2 emission performance standards for cars and vans. Available: https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en [Accessed 14 June 2024].

European Commission. (2024b). Reducing CO_2 emissions from heavy-duty vehicles. Available: https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/reducing-co2-emissions-heavy-duty-vehicles_en [Accessed 14 June 2024].

Fang, R., Le, N. & Band, P. (2011). Identification of occupational cancer risks in British Columbia, Canada: A population-based case–control study of 1,155 cases of colon cancer. *Int J Environ Res Public Health*, ***8***, 3821–3843. DOI: 10.3390/ijerp

Font, A., Hedges, M. & Han, Y. (2024). Air quality on UK diesel and hybrid trains. *Environ Int*, ***187***, 108682. DOI: 10.1016/j.envint.2024.108682

Guo, J., Kauppinen, T., Kyyrönen, P., Heikkilä, P., Lindbohm, M.,L. & Pukkala, E. (2004). Risk of esophageal, ovarian, testicular, kidney and bladder cancers and leukemia among finnish workers exposed to diesel or gasoline engine exhaust. *Int J Cancer*, ***20,*** 111(2), 286-92, PMID: 15197784. DOI: 10.1002/ijc.20263

IARC. (International Agency for Research on Cancer); working group on the evaluation of carcinogenic risks to humans (2014). Diesel and gasoline engine exhausts and some nitroarenes. *IARC Monogr Eval Carcinog Risks Hum*, ***105,*** 9-699.

Karthikeyan, S., Breznan, D., Thomson, E.M., Blais, E., Vincent, R. & Kumarathasan, P. (2024). Concordance between in vitro and in vivo relative toxic potencies of diesel exhaust particles from different biodiesel blends. *Toxics*, ***12,*** 290. DOI: 10.3390/toxics12040290

Kim, S. (2015). Package 'ppcor'. *Commun Stat Appl Methods*, ***22***(6), 665-674.

Koutros, S., Kogevinas, M., Friesen, M.C., Stewart, P.A., Baris, D., Karagas, M. R. & Silverman, D. T. (2020). Diesel exhaust and bladder cancer risk by pathologic stage and grade subtypes. *Environ Int*, ***135***, 105346. DOI: 10.1016/j.envint.2019.105346

Koutros, S., Graubard, B., Bassig, B.A., Vermeulen, R., Appel, N., Hyer, M. & Silverman, D.T. (2023). Diesel exhaust exposure and cause-specific mortality in the Diesel Exhaust in Miners Study II (DEMS II) cohort. *Environ Health Perspect*, ***131***(8), 87003. DOI: 10.1289/EHP12840

Li, T., Yang, H.L., Xu, L.T., Zhou, Y.T., Min, Y.J. & Yan, S.C. (2023). Comprehensive treatment strategy for diesel truck exhaust. *Environ. Sci. Pollut. Res. Int.*, ***30***(19), 54324-54332, DOI: 10.1007/s11356-023-26506-3

Li, X., Zhao, P., Fang, M. & Huang, Z. (2024). Organic carbon, elemental carbon, and particulate semivolatile organic compound emissions from a common-rail diesel engine: Insight into effect of fuel injection pressure at different loads. *Sci Total Environ*, ***912,*** 169465.

Lloyd, A.C. & Cackette, T.A. (2001). Diesel engines: environmental impact and control. *J. Air. Waste Manag. Assoc.*, ***51***(6), 809-847. DOI: 10.1080/10473289.2001.10464315

McCreanor, J., Cullinan, P., Nieuwenhuijsen, M.J., Stewart-Evans, J., Malliarou, E. & Jarup L. (2007). Respiratory effects of exposure to diesel traffic in persons with asthma. *N. Engl. J. Med.*, ***357***(23), 2348-58. PMID: 18057337, DOI: 10.1056/NEJMoa071535

Möhner, M. & Wendt, A. (2017). A critical review of the relationship between occupational exposure to diesel emissions and lung cancer risk. *Crit Rev Toxicol*, ***47***(3), 185-224. DOI: 10.1080/10408444.2016.1266598

Muscat, J.E. & Wynder, E.L. (1995). Diesel exhaust, diesel fumes, and laryngeal cancer. *Otolaryngology–Head and Neck Surgery*, ***112***(3), 437-440. DOI: 10.1016/s0194-5998(95)70280-6

Neophytou, A.M., Ferguson, J.M., Costello, S., Picciotto, S., Balmes, J.R. & Koutros, S. (2024). Diesel exhaust and respiratory dust exposure in miners and chronic obstructive pulmonary disease (COPD) mortality in DEMS II. *Environ. Int.*, ***185,*** 108528. PMID: 38422874, PMCID: PMC10961191. DOI: 10.1016/j.envint.2024.108528

ODMD. [Otomotiv Distribütörleri ve Mobilite Derneği (in English: Automotive Distributors and Mobility Association)] (2024). Available: https://www.odmd.org.tr/web_2837_1/rss.aspx [Accessed 14 June 2024].

Pedersen, J.E. & Hansen, J. (2023). Parental occupational exposure to chemicals and risk of breast cancer in female offspring. *Environ Res.*, ***227***, 115817; Epub 1, April 2023. PMID: 37011793. DOI: 10.1016/j.envres.2023.115817

Pedersen, J.E., Strandberg-Larsen, K., Andersson, M. & Hansen, J. (2012). Breast cancer among Danish women occupationally exposed to diesel exhaust and polycyclic aromatic hydrocarbons, 1964-2016. *Scand J Work Environ Health*, ***47***(2), 154-162. DOI: 10.5271/sjweh.3920

Peyre-Costa, D., Stjernbrandt, A., Wahlström, J., Ikäheimo, T.M. & Höper, A.C. (2024). Self-reported exposure to dust and diesel exhaust, respiratory symptoms, and use of respiratory

protective equipment among Arctic miners. *Int J Circumpolar Health*, ***83***(1), 2343125. PMID: 38626426; PMCID: PMC11022915. DOI: 10.1080/22423982.2024.2343125

Petersen, A., Hansen, J., Olsen, J. H. & Netterstrøm, B. (2010). Cancer morbidity among Danish male urban bus drivers: a historical cohort study. *American Journal of Industrial Medicine*, ***53***(7), 757-761.

Pirhadi, M., Krasowsky, T.S., Gatt, G. & Quiros, D.C. (2024). Criteria pollutant and greenhouse gas emissions from cargo handling equipment operating at the Ports of Los Angeles and Long Beach. *Science of the Total Environment*, ***927***, 172084.

Ptak, M., Neneman, J. & Roszkowska, S. (2024). The impact of petrol and diesel oil taxes in EU member states on CO2 emissions from passenger cars. *Scientific Reports*, ***14***(1), 52. DOI: 10.1038/s41598-023-50456-y

Richiardi, L., Mirabelli, D., Calisti, R., Ottino, A., Ferrando, A., Boffetta, P. & Merletti, F. (2006). Occupational exposure to diesel exhausts and risk for lung cancer in a population-based case–control study in Italy. *Annals of Oncology*, ***17***(12), 1842-1847.

Romero, S.K., Bolm-Audorff, U., Reissig, D. & Seidler, A. (2024). Dose-response-relationship between occupational exposure to diesel engine emissions and lung cancer risk: A systematic review and meta-analysis. *International Journal Of Hygiene And Environmental Health*, ***256,*** 114299. DOI: 10.1016/j.ijheh.2023.114299

Sabanov, S., Qureshi, A.R., Korshunova, R. & Kurmangazy, G. (2024). Analysis of Experimental Measurements of Particulate Matter (PM) and Lung Deposition Surface Area (LDSA) in Operational Faces of an Oil Shale Underground Mine. *Atmosphere*, ***15***, 200. DOI: 10.3390/atmos15020200

Saini, N., Negi, M., Yadav, P. & Singh, R. (2024). Oxidative desulfurization of fuels using alcohol-based DESs. *Environ Sci Pollut Res Int*, ***1***, 22. DOI: 10.1007/s11356-024-33093-4

Sassano, M., Collatuzzo, G., Teglia, F. & Boffetta P. (2024). Occupational exposure to diesel exhausts and liver and pancreatic cancers: a systematic review and meta-analysis. *Eur J Epidemiol*, ***39***(3), 241-255. DOI: 10.1007/s10654-024-01099-4.

Seo, J., Park, J., Oh, Y. & Park, S. (2016). Estimation of total transport CO2 emissions generated by medium- and heavy-duty vehicles (MHDVs) in a sector of Korea. *Energies*, ***9***, 638.

Shammut, M., Cao, M., Zhang, Y., Papaix, C., Liu, Y. & Gao, X. (2019). Banning diesel vehicles in London: Is 2040 too late? *Energies*, ***12***(18), 3495. DOI: 10.3390/en12183495

Soll-Johanning H., Bach, E. & Jensen, S.S. (2003). Lung and bladder cancer among Danish urban bus drivers and tramway employees: a nested case-control study. *Occupational Medicine*, ***53***(1), 25-33. DOI: 10.1093/occmed/kqg004

Talibov, M., Sormunen, J., Weiderpass, E., Kjaerheim, K., Martinsen, J.I. & Sparen P. (2019). Workplace Diesel Exhausts and Gasoline Exposure and Risk of Colorectal Cancer in Four Nordic Countries. *Safety And Health at Work*, ***10***(2), 141-150. DOI: 10.1016/j.shaw.2019.01.001

Tian, S., Liu, Q., Ge, S., Luo, L., Yang, M. & An, Y. (2024). Characteristics of Polycyclic Aromatic Hydrocarbons in Size-Re solved Particles in the Roadside Environment of Beijing: Seasonality, Source, and Toxicological Effects. *Atmosphere*, ***15,*** 346. DOI: 10.3390/atmos15030346

TurkStat. (Turkish Statistical Institute) (2022). Death and Death Causes Statistics. Available: https://data.tuik.gov.tr/Bulten/Index?p=Olum-ve-Olum-Nedeni-Istatistikleri-2022-49679 [Accessed 14 June 2024].

TurkStat (Turkish Statistical Institute) (2023a). Road motor vehicles, July 2023. Available: https://data.tuik.gov.tr/Bulten/Index?p=Road-Motor-Vehicles-July-2023-49428&dil=2 [Accessed 14 June 2024].

TurkStat (Turkish Statistical Institute) (2023b). Turkish Greenhouse Gas Inventory 1990–2021. *National Inventory Report for Submission Under the United Nations Framework Convention on Climate Change*. https://enerji.gov.tr/Media/Dizin/EVCED/tr/%C3%87evreVe%C4%B0klim/%C4%B0klimDe%C4%9Fi%C5%9Fikli%C4%9Fi/UlusalSeraGaz%C4%B1EmisyonEnvanteri/Belgeler/Ek-1.pdf

Vahter, M., Gochfeld, M., Casati, B., Thiruchelvam, M., Falk-Filippson, A. & Kavlock, R. (2007). Implications of gender differences for human health risk assessment and toxicology. *Environmental Research*, ***104***(1), 70-84. DOI: 10.1016/j.envres.2006.10.001

Zhang, H., Taya, K., Nagaoka, K., Yoshida, M. & Watanabe, G. (2017). 4-Nitrophenol (PNP) inhibits the expression of estrogen receptor β and disrupts steroidogenesis during the ovarian development in female rats. *Environmental Pollution*, ***229***, 1-9. DOI: 10.1016/j.envpol.2017.04.088