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Original Article

Estimates of the Number of Workers Exposed to Diesel Engine Exhaust in South Korea from 1993 to 2013

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ABSTRACT

Background: The aim of this study was to estimate the number of workers exposed to diesel engine exhaust (DEE) by industry and year in the Republic of Korea.

Method: The estimates of workers potentially exposed to DEE in the Republic of Korea were calculated by industry on the basis of the carcinogen exposure (CAREX) surveillance system. The data on the labor force employed in DEE exposure industries were obtained from the Census on Establishments conducted by the Korea National Statistical Office from 1993 to 2013. The mean values of prevalence rates adopted by EU15 countries were used as the primary exposure prevalence rates. We also investigated the exposure prevalence rates and exposure characteristics of DEE in 359 workplaces representing 11 industries.

Results: The total number of workers exposed to DEE were estimated as 270,014 in 1993 and 417,034 in 2013 (2.2% of the total labor force). As of 2013, the industry categorized as “Land transport” showed the highest number of workers exposed to DEE with 174,359, followed by “Personal and household services” with 70,298, “Construction” with 45,555, “Wholesale and retail trade and restaurants and hotels” with 44,005, and “Sanitation and similar services” with 12,584. These five industries, with more than 10,000 workers exposed to DEE, accounted for 83% of the total DEE-exposed workers. Comparing primary prevalence rates used for preliminary estimation among 49 industries, “Metal ore mining” had the highest rate at 52.6%, followed by “Other mining” with 50.0%, and “Land transport” with 23.6%.

Conclusion: The DEE prevalence rates we surveyed (1.3–19.8%) were higher than the primary prevalence rates. The most common emission sources of DEE were diesel engine vehicles such as forklifts, trucks, and vans. Our estimated numbers of workers exposed to DEE can be used to identify industries with workers requiring protection from potential exposure to DEE in the Republic of Korea.

1. Introduction

Diesel engines power a large portion of land and sea transport and generate the electricity required in numerous farming, construction, and industrial activities [1]. Exposure to diesel engine exhaust (DEE) is currently widespread due to the increasing volume of motor vehicles and machinery using diesel fuel. DEE consists of hundreds of gas-phase, semivolatile, and particle-phase organic compounds that are produced through the combustion of this fossil fuel [1].

In 2012, based on sufficient available evidence that exposure to it is associated with an increased risk for lung cancer, DEE was

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reclassified by the International Agency for Research on Cancer (IARC) from probably carcinogenic to humans (Group 2A) to carcinogenic to humans (Group 1) [2]. IARC also noted that DEE has a positive association (based on limited evidence) with an increased risk of bladder cancer.

One of the major challenges in occupational cancer prevention is a lack of knowledge regarding precisely where carcinogenic exposures are occurring and the number of workers affected. To create an exposure surveillance system supporting the effective prevention of occupational cancer, it is necessary for a country to build a basic database to perform surveillance on the number of workers exposed to carcinogens and their distribution according to type of industry, occupation, and other exposure variables. The carcinogen exposure (CAREX) system is an international information system for estimating the numbers of workers exposed to known (Group 1) and suspected (Group 2A) carcinogens as classified by the IARC. Estimates on occupational exposure to carcinogens in the European Union (EU) in the 1990s, including DEE, have been published [3,4]. CAREX was subsequently adapted to serve as a carcinogen exposure surveillance system in several countries [5–7]. No estimates have as yet been produced for Asia, including for the Republic of Korea.

The aims of this study were to estimate the number of workers exposed to DEE by industry and by year in the Republic of Korea using the CAREX method, to compare our estimates with results from other countries in which the CAREX method has been applied, and to investigate the DEE prevalence rate for several industries.

2. Materials and methods

The CAREX surveillance system has already been fully explained elsewhere [3–6]. A brief description of the assessment procedures used to estimate the number of workers exposed to DEE in this study is presented here as Fig. 1.

Firstly, all industries projected by the CAREX results from the 15 EU countries were listed. The 49 industries with an exposure prevalence rate were first referred to as "industries with the possibility of DEE exposure" (hereafter referred to as DEE exposure industry). Industries with an International Standard Industrial Code (ISIC) revision 2 were reclassified according to the three-digit level of the Korea Standard Industrial Classification (KSIC) revisions 8 and 9. Some nonmanufacturing sectors were classified at the one- or two-digit levels.

Secondly, data on the labor force employed in DEE exposure industries were obtained from the "Census on Establishments" (a nationwide annual census on the characteristics of enterprises with one or more employees doing business in Korea) conducted by the Korea National Statistical Office from 1993 to 2013 [8]. The industrial classes of the labor force from 1993 to 2005 and from 2006 to 2013 were coded at the three-digit level of KSIC revisions 8 and 9, respectively. These labor force figures cover all workers, including self-employed workers, working family members, and part-time workers.

Thirdly, the estimates of workers potentially exposed to DEE were calculated on the basis of the CAREX system, multiplying the labor force by the primary prevalence rate of the industry concerned. In this study, we used the mean value of prevalence rates adopted by the EU15 countries as the primary prevalence rate for estimation of DEE exposure.

Finally, our field investigation of DEE exposure rates from 11 DEE exposure industries were compared with those estimated for EU countries. We investigated 359 workplaces where workers were exposed DEE in order to obtain DEE exposure prevalence rates. Because of the lack of airborne DEE levels or industrial hygiene data to assess DEE exposure, we qualitatively assessed DEE exposure among the overall workforce in terms of the workers involved, how, and what type of job. Workers who drive diesel vehicles or work near the operation of such vehicles or who work in a space where diesel fuel is used by vehicles or mechanical instruments were considered workers exposed to DEE. Exposure to DEE over more than 75% of the working hours was regarded as the minimum DEE exposure duration guideline as indicated by the CAREX system. The surveyed prevalence rates were compared with the primary prevalence rates.

3. Results

3.1. Number of workers exposed to DEE by industry and year

The number of workers exposed to DEE from among the total labor force and in DEE exposure industries has been on the rise from 1993 until 2013 (Fig. 2). The total number of workers exposed

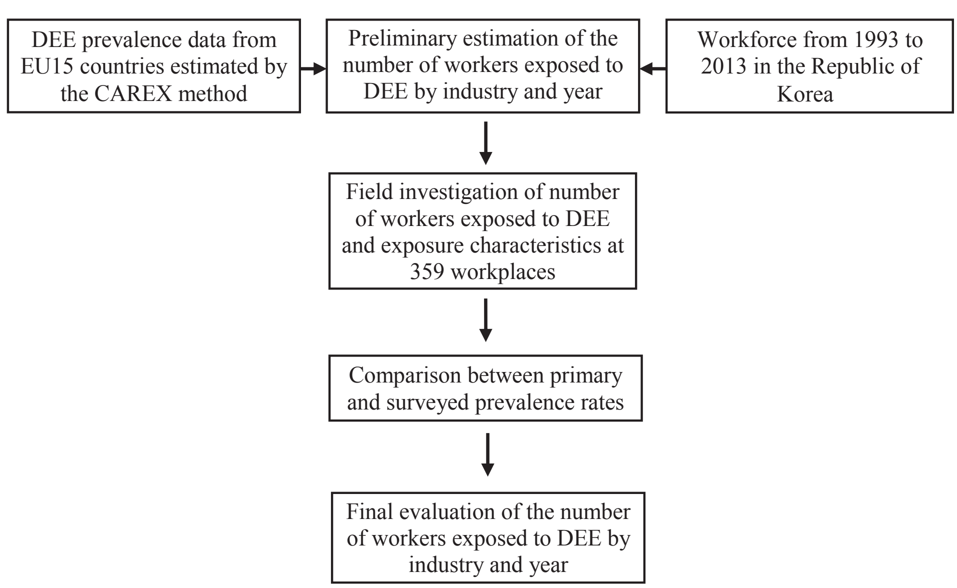

Fig. 1. Procedure for estimating the numbers of workers exposed to diesel engine exhaust (DEE) in the Republic of Korea. CAREX, carcinogen exposure system; EU, European Union.

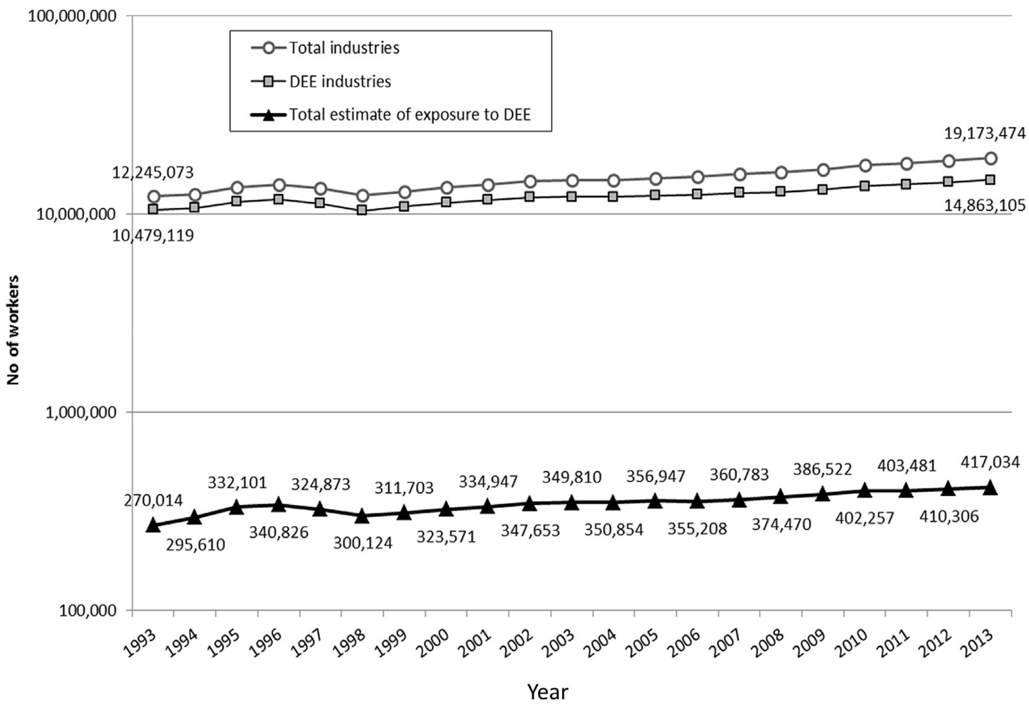

Fig. 2. Number of workers of total industries, diesel engine exhaust (DEE) exposure industries and total estimate of exposure to DEE from 1993 to 2013.

to DEE ranged from 270,014 in 1993 to 417,034 in 2013 (2.2% of the total labor force).

These numbers are also described by industry in a four-year interval in Table 1. Fig. 3 shows the five major industries that make up the DEE exposure estimates from 1993 to 2013.

As of 2013, the "Land transport" designation (KSIC revision 9 code: 49) showed the highest number of workers exposed to DEE (174,359), followed by "Personal and household services" (KSIC revision 9 code: 95, 96) with 70,298, "Construction" (KSIC revision 9 code: 41, 42) with 45,555, "Wholesale and retail trade and restaurants and hotels" (KSIC revision 9 code: 45, 46, 47, 55, 56) with 44,005, and "Sanitation and similar services" (KSIC revision 9 code: 37, 38, 39, 742) with 12,584. These five industries showing over 10,000 workers exposed to DEE accounted for 83% of the total DEE-exposed workers. Comparing primary prevalence rates among 49 industries, "Metal ore mining" (KSIC revision 9 code: 06) had the highest rate at 52.6%, followed by "Other mining" (KSIC revision 9 code: 07) with 50.0%, and "Land transport" with 23.6%.

3.2. Comparison of DEE exposure estimates in the Republic of Korea with EU CAREX

The estimated number of workers exposed to DEE and DEE exposure prevalence rates were compared with results from other countries to which the CAREX method had been applied (Table 2). The average DEE exposure prevalence rate in the total work force from 1993 to 2013 (2.2%) was generally similar to those estimated in the 15 EU countries where it ranged from 1.7% to 3.2%.

3.3. Field investigation of exposure prevalence rate and exposure characteristics of DEE

Our DEE exposure prevalence rates as investigated in 11 DEE exposure industries were compared with the EU results (Table 3). They ranged from 1.3% to 19.8%, and were found to be generally higher than the primary prevalence rates estimated in EU countries. The most common tasks in the DEE exposure group were: (1) delivery of materials or persons with diesel-engine vehicles such as forklifts, trucks, vans, and ambulances; (2) the management of facilities with emergency generators; and (3) operation of diesel-engine equipment, including cleaning and metal-working machinery.

4. Discussion

We found that a total of 49 industries were estimated to feature a potential for DEE exposure higher than to the airborne level commonly found in the outdoor environment (Table 1). The industry with the most common DEE exposure was found to be "Land transport", which accounted for 41.8% of the total DEE exposure estimates in 2013, followed by "Personal and household services" (16.9%), "Construction" (10.9%), "Wholesale and retail trade and restaurants and hotels" (10.9%), and "Sanitation and similar services" (3%; (Fig. 3). Our results were generally found to be similar to those estimated in the EU CAREX: "Land transport" (32.8%), "Construction" (21.6%), "Personal and household services" (10.5%), "Other mining" (4.4%), and "Wholesale and retail trade and restaurants and hotels" (3.9%). There appears to be a possibility of underestimating the number of DEE-exposed workers in "Construction" due to the high proportion of temporary workers who are not included in the related workforce. The employment rate of temporary workers in this industry in Korea increased from 16.6% in 2001 to 29.7% in 2004, which were evaluated as the second highest among Organization for Economic Co-operation and Development countries in 2007 [9] and showing the fastest rate of change.

The average number of workers (1993–2013) estimated to be exposed to DEE in the Republic of Korea was identified as lower than those in Italy (552,495), the UK (473,062), Germany (741,443), and France (410,499; Table 2), although the reference year of estimation and total workforce differed among countries. The CAREX project estimated about 3 million workers in the EU15 countries in

Table 1
Number of workers exposed to diesel engine exhaust (DEE) from 1993 to 2013 by industry

Industry	Industry code			Reference country	Primary prevalence rate* (%)	DEE exposure estimate by y					
	ISIC revision 2	KSIC revision 8	KSIC revision 9			1993	1997	2001	2005	2009	2013
Land transport	711	60	49	FIN, USA	23.6	89,162	124,061	144,185	148,672	172,773	174,359
Personal and household services	95	92, 93, 95	95, 96	FIN	10.0	40,258	45,441	51,216	55,876	61,544	70,298
Construction	5	45, 46	41, 42	FIN, USA, FRA	4.4	28,661	42,407	27,692	34,153	39,174	45,555
Wholesale and retail trade and restaurants and hotels	6	50, 51, 52, 55	45, 46, 47, 55, 56	FIN, FRA	0.90	30,485	34,886	37,367	37,369	39,603	44,005
Sanitation and similar services	92	90, 759	37, 38, 39, 742	FIN, USA, ITA	6.7	5,898	8,094	10,794	16,569	9,735	12,584
Services allied to transport	719	631, 632, 633	521, 752	FIN, USA	8.2	5,382	6,077	6,620	8,124	6,712	7,914
Other mining	29	12	07	FIN	50.0	11,894	9,427	6,887	6,661	6,581	6,096
Manufacture of fabricated metal products, except machinery and equipment	381	28	251, 259	FIN, USA	1.3	3,289	3,295	3,602	4,366	4,804	5,606
Manufacture of other nonmetallic mineral products	369	263, 269	233, 239	FIN, USA	8.6	8,261	7,419	6,001	5,279	5,032	5,299
Manufacture of plastic products not elsewhere classified	356	252	222	USA, FRA	2.3	2,416	2,374	3,257	4,000	4,074	4,948
Water transport	712	61	50	FIN, USA	19.1	3,389	3,030	3,181	3,030	4,446	3,678
Public administration and defense	91	76	84	FIN, ITA	0.48	2,417	2,800	2,524	2,570	3,143	3,075
Manufacture of transport equipment	384	34, 35	30, 31	FIN, USA	0.56	2,088	1,974	1,902	2,098	2,362	2,889
Iron and steel basic industries	371	271, 273	241, 243	FIN, USA	2.0	2,591	1,771	1,835	1,882	1,995	2,370
Food manufacturing	311, 312	151, 152, 153, 154	10	FIN, USA, FRA	0.80	2,314	2,222	2,240	2,215	2,101	2,288
Manufacture of machinery except electrical	382	291, 292, 293, 300	263, 29	FIN, USA	0.46	1,510	1,369	1,605	1,668	1,626	1,980
Air transport	713	62	51	USA	7.1	2,127	455	970	1,037	1,234	1,939
Manufacture of electrical machinery apparatus, appliances, and supplies	383	295, 31, 32	26, 28	FIN, USA	0.25	1,230	1,174	1,305	1,537	1,422	1,671
Forestry and logging	12	02	02	DEN, FRA	23.5	122	309	453	751	876	1,478
Water works and supply	42	41	36	USA	9.1	395	835	1,194	1,378	1,334	1,436
Communication	72	64	61	USA	1.4	1,028	1,229	2,019	1,892	1,353	1,337
Nonferrous metal basic industries	372	272, 273	242, 243	USA	3.4	1,255	1,138	1,143	1,062	1,105	1,332
Agriculture and hunting	11	01	01	DEN, FRA	5.5	356	1,303	1,294	1,257	1,149	1,268
Manufacture of pottery, china, and earthenware	361	262	232	FRA, ITA	7.1	2,899	1,959	1,657	1,305	1,140	1,184
Fishing	13	05	03	FRA, ITA	21.4	4,104	7,509	2,164	1,343	1,023	1,118
Manufacture of wood and wood and cork products, except furniture	331	20	16	FIN, USA	3.0	1,871	1,436	1,325	1,232	1,028	1,066
Electricity, gas, and steam	41	40	35	USA, FRA	1.8	624	735	830	929	961	952
Manufacture of industrial chemicals	351	241, 244	201, 202, 203, 205	FIN, USA	1.2	1,117	1,027	945	854	769	932
Manufacture of other chemical products	352	242, 243, 294	204, 21, 252	USA	0.8	955	911	912	845	750	894
Beverage industries	313	155	11	FIN, USA	5.3	1,968	1,183	1,278	1,041	843	872
Manufacture of rubber products	355	251	221	FRA, ITA, NET	1.6	826	622	661	733	688	849
Manufacture of textiles	321	17	13	USA	0.6	2,237	1,508	1,480	1,050	772	833
Medical, dental, other health and veterinary services	933	85	86, 731	USA, ITA	0.1	234	309	385	487	624	768
Manufacture of paper and paper products	341	21	17	FIN, USA	1.0	777	709	702	657	615	708
Education services	921	80	85	FRA	0.04	282	347	437	519	591	649
Printing, publishing, and allied industries	342	22	18, 58	USA	0.17	255	234	239	231	419	484
Petroleum refineries	353	232	192	USA	4.6	661	738	462	445	482	455
Manufacture of wearing apparel, except footwear	322	18	14	FIN, USA	0.29	979	609	563	434	418	418
Other manufacturing industries	39	369	33	USA	0.55	614	483	465	394	323	352

(continued on next page)

Table 1 (*continued*)

Industry	Industry code			Reference country	Primary prevalence rate* (%)	DEE exposure estimate by y					
	ISIC revision 2	KSIC revision 8	KSIC revision 9			1993	1997	2001	2005	2009	2013
Manufacture of furniture and fixtures, except primarily of metal	332	361	32	USA	0.35	222	203	216	221	215	235
Metal ore mining	23	11	06	FIN	52.6	1,324	372	162	118	128	213
Manufacture of professional and scientific, and measuring and controlling equipment not elsewhere classified	385	33	27	USA	0.18	98	106	118	127	140	193
Manufacture of leather and products of leather, leather substitutes and fur, except footwear and wearing apparel	323	191, 192	151	FRA, ITA	1.1	374	282	253	167	128	181
Manufacture of footwear, except vulcanized or molded rubber or plastic footwear	324	193	152	FRA, ITA	0.55	504	243	216	127	107	107
Manufacture of glass and glass products	362	261	231	FIN, USA	0.24	74	61	57	67	72	72
Coal mining	21	101	051	FRA	1.8	471	191	126	98	67	49
Manufacture of miscellaneous products of petroleum and coal	354	231	191	USA	3.4	10	4	2	0	28	33
Crude petroleum and natural gas production	22	102	052	USA	14.1	0	0	1	76	12	9
Tobacco manufactures	314	16	12	FIN, USA	0.12	8	6	3	4	3	2
Total DEE exposure industries						270,014	324,873	334,947	356,947	386,522	417,034

* Primary prevalence rate was presented as the mean value of reference countries.
DEN, Denmark; FIN, Finland; FRA, France; ISIC, International Standard Industrial Classification; ITA, Italy; KSIC, Korea Standard Industry Code; NET, Netherland; USA, The United States of America.

1990–1993 were exposed to DEE. Our average DEE exposure prevalence rates for the total workforce (2.2% for 1993 and 2013) fell within the range of 1.9% in France to 3.2% in Italy, which were far lower than the 21.3% estimated in Costa Rica [10].

The number of workers in the Republic of Korea exposed to DEE according to the CAREX system was first estimated. The CAREX system can be applied to different counties provided that reasonably accurate labor statistics are available. We used labor force data from the "Census on Establishments" conducted by the Korea National Statistical Office. This survey covers all establishments in the Republic of Korea as of December 31, excluding agricultural, forestry, and fishery firms managed by an individual, national defense, private household services, international or foreign organizations, and irregular direct sales operations lacking fixed facilities. To accurately estimate the number of workers exposed to DEE by industry, conversions between different industrial coding systems had to be conducted in the processing of labor force statistics and CAREX exposure prevalence data. The CAREX data were originally coded according to ISIC revision 2, but KSIC revisions 8 and 9 were based on ISIC revisions 3 and 4, respectively. Most of the DEE exposed industry codes could in fact be matched correctly, with the exception of a few industries. Under the ISIC revision 2 system, the manufacturing of pesticides is not classified into "Manufacture of other chemical products" (ISIC revision 2 code: 352) but as "Manufacture of industrial chemicals" (ISIC revision 2 code: 351). However, the KSIC system classifies the manufacturing of pesticides as the manufacturing of other chemical products. In terms of "Basic metal industry" (ISIC revision 2 code: 37), the ISIC system had just two classifications at the three-digit level ["Iron and steel basic industries" (371) and "Nonferrous metal basic industries" (372)], whereas KSIC features an additional classification of "Metal foundry" (KSIC revision 8 code: 273 and 9 code: 243). Therefore, according to the ratio of ferrous- to nonferrous-metal basic industries, 78% and 22% of the workers in "Metal foundry" were added to the number of workers in "Iron and steel basic industries" and "Nonferrous metal basic industries", respectively. For "Land transport" (711), "Water transport" (712), and "Air transport" (713), they also include supporting services, such as the operation of terminals, piers, and airports, respectively. Under the KSIC system, all workers in supporting services for land, water, and air transport are separately classified as "Services allied to transport" (719).

Another important factor for an accurate estimation through CAREX is the appropriate selection of exposure prevalence rates. For the CAREX system, most estimates were derived indirectly on the basis of information from two reference countries with reasonably comprehensive data (Finland and the USA) [4]. The CAREX study team reported that the Finnish approach generally sets the minimum exposure at a higher level compared with the USA approach, and results therefore in lower proportions of exposed workers [4]. For 15 industries, including "Agriculture and hunting", Denmark, France, Italy, and the Netherlands produced estimates which are adjusted for the labor force structure and account for exposure patterns in these countries. However, the adjustment of default estimates to correspond with national conditions has turned out to be problematic due to related variability. Therefore, we decided to utilize the average value of the prevalence rates adopted in EU CAREX estimates to the greatest extent possible in order to reduce the variability.

We investigated the prevalence rate of DEE exposure for 11 DEE exposure industries and compared them with the primary prevalence rate based on several reference countries (Table 3). All of the surveyed prevalence rates showed higher values than the primary prevalence rates estimated according to the CAREX method, despite the limitation on examining if the workplaces selected fully represent the breadth of the 11 DEE exposure

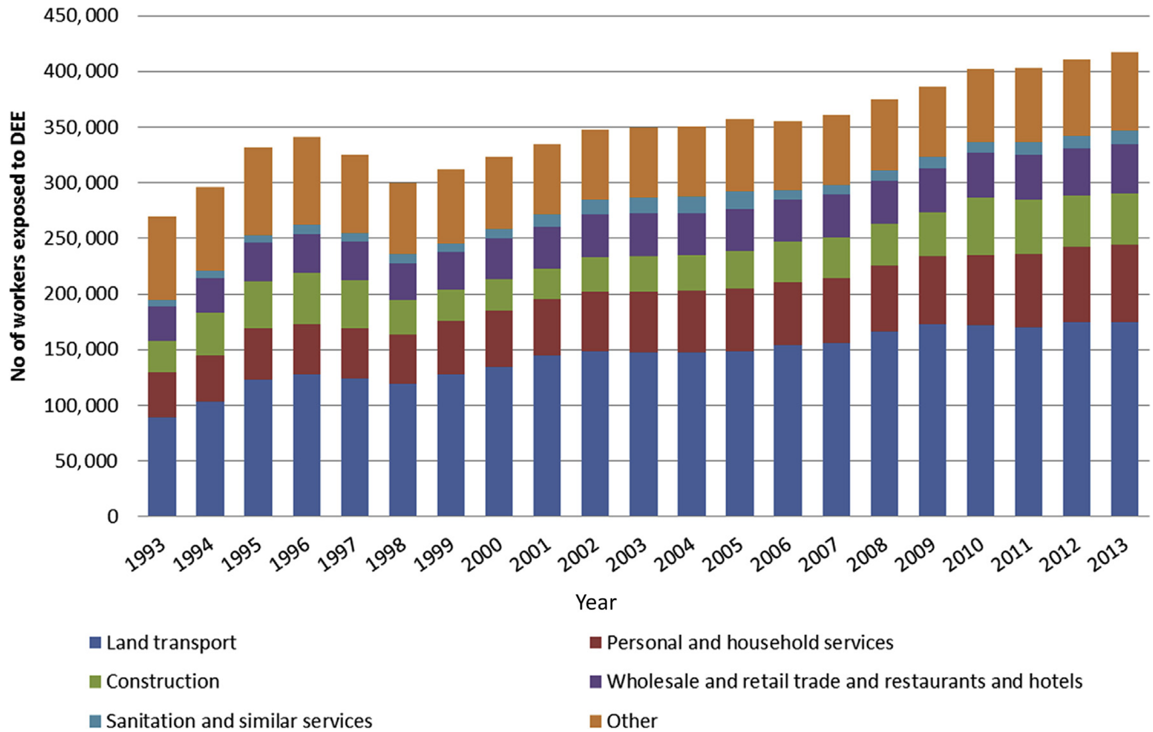

Fig. 3. Major industries that comprise the diesel engine exhaust (DEE) exposure estimates from 1993 to 2013.

Table 2
Comparison of estimated number of workers exposed to diesel engine exhaust (DEE) by country

Country	Total workforce	Total employees in DEE exposure industry	No. of workers exposed to DEE	Prevalence rate within total workforce* (%)	Prevalence rate within DE industry† (%)	Y estimated
Austria	3,086,425	2,126,450	79,300	2.6	3.7	1990–1993
Belgium	3,506,842	2,294,407	67,051	1.9	2.9	1990–1993
Denmark	2,812,902	1,807,507	71,331	2.5	3.9	1990–1993
Finland	2,138,381	1,024,335	38,490	1.8	3.8	1990–1993
France	21,786,228	18,319,703	410,499	1.9	2.2	1990–1993
Germany	34,035,522	23,759,879	741,443	2.2	3.1	1990–1993
Greece	3,332,580	1,908,777	78,546	2.4	4.1	1990–1993
Ireland	1,088,450	636,626	21,075	1.9	3.3	1990–1993
Italy	17,073,393	13,800,125	552,495	3.2	4.0	1990–1993
Luxembourg	186,493	131,913	4,394	2.4	3.3	1990–1993
Netherlands	6,463,694	3,977,161	108,934	1.7	2.7	1990–1993
Portugal	4,019,845	2,538,389	73,176	1.8	2.9	1990–1993
Spain	12,162,830	8,021,270	274,321	2.3	3.4	1990–1993
Sweden	4,003,674	2,186,882	80,625	2.0	3.7	1990–1993
UK	22,821,375	14,874,425	473,062	2.1	3.2	1990–1993
15 EU total	138,518,634	97,407,849	3,074,742	2.2	3.2	1990–1993
Republic of Korea	12,245,073	10,479,119	270,014	2.2	2.6	1993
	13,470,343	11,264,620	324,873	2.4	2.9	1997
	14,109,641	11,765,619	334,947	2.4	2.8	2001
	15,147,471	12,413,643	356,947	2.4	2.9	2005
	16,818,015	13,232,999	386,522	2.3	2.9	2009
	19,173,474	14,863,105	417,034	2.2	2.8	2013

* Prevalence rate within total workforce was calculated as the number of workers exposed to DEE divided by the total workforce.
† Prevalence rate within DE exposure industry was calculated as the number of workers exposed to DEE divided by the total employees in DEE exposure industries.
EU, European Union.

industries. For example, with the "Personal and household services" industry, which had the highest prevalence rate at 19.8%, 77% of the workplaces (10/13) investigated were in the category of "General repair services of motor vehicles" (KSIC revision 9 code: 95211). Although "Personal and household services" consisted of 31 fields classified at the five-digit level, we were able to collect information from only three of them. In order to acquire a more accurate exposure prevalence, it is necessary to conduct more systematic surveillance covering all industries. Our field investigation results indicated that DEE prevalence rates estimated

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Table 3
Summary of the prevalence rates and exposure characteristics of diesel engine exhaust (DEE) in 11 industries as identified through field investigation

Industry	No. of workplaces	Total employees	No. of workers exposed to DEE	Surveyed prevalence rate (%)	Primary prevalence rate (%)	Major tasks of DEE exposure group	DEE emission source
Manufacture of fabricated metal products, except machinery and equipment	65	1,483	117	7.89	1.34	Material delivery	Forklift, truck
Manufacture of machinery except electrical	63	1,918	123	6.41	0.46	Material delivery	Forklift, truck
Manufacture of transport equipment	57	9,294	536	5.77	0.56	Material delivery Auto-vehicle test	Forklift, truck
Medical, dental, other health and veterinary services	47	5,138	67	1.30	0.10	Facilities management Transportation of patients	Emergency generator Ambulance
Iron and steel basic industries	37	1,297	68	5.24	1.98	Material delivery	Forklift, truck
Wholesale and retail trade and restaurants and hotels	26	1,755	113	6.44	0.90	Facilities management Material delivery	Emergency generator Forklift, truck, van
Manufacture of electrical machinery apparatus, appliances, and supplies	19	437	30	6.86	0.25	Facilities management Material delivery	Emergency generator Forklift, truck
Personal and household services	13	177	35	19.77	10.04	Material delivery Cleaning in car repair shop	Truck Cleaning equipment
Nonferrous metal basic industries	12	334	19	5.69	3.35	Material delivery Metalworking	Forklift, truck Metalworking machinery
Manufacture of plastic products not elsewhere classified	10	237	17	7.17	2.31	Material delivery	Forklift, truck, van
Food manufacturing	10	294	20	6.80	0.80	Material delivery	Forklift, truck
Total	359	22,364	1,145	5.12			

directly based on the CAREX method need to be refined according to the structure and employment characteristics of the country applying the method.

In accordance with the following considerations, DEE exposure prevalence as estimated based on the CAREX method in the 15 EU countries was directly applied to national circumstances in the Republic of Korea without updating DEE prevalence rates. To our knowledge, there has been no substantial change in legislation that may lead to considerable variations in the prevalence rate or in the probability of DEE exposure by industry in the Republic of Korea from the 1990s to date. Furthermore, no literature to date has reported on either DEE occupational exposure or health effects related to DEE in the Republic of Korea. Despite the carcinogenicity of DEE, there have been no proportionately strict measures to control DEE exposure in occupational settings. Exposure assessment as has been legally implemented for other carcinogens has not yet been required for DEE. Trend analysis of past exposures indicates that regulations, technology, and labor safety measures may strongly influence both the prevalence and the level of exposure [11]. Different legislative frameworks may lead to considerable variations in exposure patterns between countries, as is the case with asbestos or passive smoking at work [4].

There are specific factors able to substantially influence the DEE exposure prevalence rate in an occupational setting. The main factor for determining the probability of DEE exposure is the indoor or outdoor use and repair and/or testing of diesel-powered vehicles or diesel mechanical instruments, although the airborne level of DEE exposure involved is associated with the size, number, and duration of use of diesel engines and the degree of ventilation. It has become widely known that the major source of occupational exposure to DEE is from vehicles using diesel fuel, such as buses, trains, ferries, trucks, tractors, and forklift trucks. According to European vehicle market statistics [12], the average market share of diesel passenger cars in 27 European countries has risen from 36% in 2001 to 55% in 2012. In the Republic of Korea, the proportion of diesel vehicles among all newly registered cars has also been increasing, from 28% in 1997 to 38.1% in 2012, although it remains lower than that in European countries [13,14].

DEE is also generated from stationary power sources which may be used in tunnels, alongside railway lines during maintenance work and on construction sites. Enclosure of the work site and type of diesel equipment used are the most important determinants affecting occupational DEE exposure [15].

Studies of indoor diesel contributions have focused on occupational exposure, such as in mines or warehouses, and on jobs or tasks using diesel-powered vehicles or diesel mechanical instruments. Metal ore mining and other mining industries have been estimated to have the highest DEE exposure prevalence rate. In order to investigate DEE exposure prevalence rates, it is important to determine where diesel engine-powered vehicles and machinery have been used and when they were either introduced or abolished. They may have been replaced with new technologies at a certain point, such as hybrids, fuel cells, or electronic vehicles, which can substantially influence the probability of DEE exposure. The use of diesel forklifts for lifting and transporting materials or products over short distances either within or between operations causes not only their drivers, but also all the workers within the same operation to be exposed to DEE. For example, our investigation into the prevalence rate at one large-vehicle tire manufacturing plant employing 2,652 workers found that a total of 46 forklift trucks were used to transport products or material either between or within operations, resulting in direct exposure to DEE on the part of 60 drivers, and indirect exposure among workers working near the operation of these trucks (data not shown here).

During the 1990s, exhaust emissions from forklift operations began to be addressed, which led to emission standards for forklift manufacturers being implemented in various countries [1]. Due to the lack of any official data on the size of diesel vehicles by industry, it cannot be generalized into a prevalence rate. The introduction of electric forklifts and fuel cell technology can result in zero local emissions. There has been no legislation or guidelines enforced in Korea regarding banning or limiting the use of diesel-powered vehicles or diesel mechanical instruments in industry. In addition, the number of diesel-powered vehicles used in workplaces has not been reported. In particular, many off-road applications, such as in ships, trains, bulldozers, locomotives, forklift trucks, construction, distribution, farming, and the military, as well as diesel generators, are still largely uncontrolled worldwide [1]. Off-road vehicle turnover is low and older engines are generally used longer in off-road than in on-road vehicles [12]. In order to examine DEE prevalence rates, further study should be conducted to investigate the number and size of diesel-powered vehicles or diesel mechanical instruments used by industry.

The strengths and limitations of CAREX have been described elsewhere [4,6]. Briefly, the CAREX assessment method as applied shows a number of advantages, such as its systematic approach, wide coverage of industries and countries, ease of use, use of national experts, comprehensive documentation, and generalizability of the estimation process [4]. A single harmonized assessment method can be applied to respective countries, which improves the comparability of the estimates across countries. The reliability of the estimates should be improved by incorporating field investigation into DEE exposure prevalence in DEE exposure industries. Some of the differences between estimates are likely to result from not only methodological factors, but also differences in industry structure among countries.

Several factors should be considered when the CAREX system is used to estimate DEE exposure industries and the number of workers exposed to DEE in the Republic of Korea.

Firstly, the CAREX approach may neglect a portion of the exposure stemming from miscellaneous operations in many industries. The CAREX data on DEE may also be considered rather crude, since DEE was only one out of the 85 carcinogens assessed initially by CAREX and the method used was less detailed and databased than the present procedures. Comparisons across countries could be partly hampered by the lack of detailed estimation procedures by specific carcinogen. It is unclear for DEE exposure industries whether to include the exposures of scattered self-employed workers who either drive diesel engine vehicles or possess on-road or off-road diesel vehicles, as well as whether to include several jobs with the possibility of potential high exposure to DEE. There remains the question of whether workers such as police officers, traffic wardens, and toll booth operators who are occupationally exposed to DEE should be included in DEE exposure industries. Workers in toll booths can be exposed to diesel and gasoline engine exhaust emissions. The total number of toll booth workers in Korea is 4,958 as of 2013. Jobs with exposure to trafficked streets, such as those found in a significant proportion of bars, restaurants, shops, stands, and street-side vending, were not included. It is also unclear whether to consider occupational exposure among those in direct contact with diesel vehicles in operations where manufactured products are loaded in diesel vehicles either outdoors or indoors in manufacturing and nonmanufacturing industries.

Secondly, the numbers of workers exposed to carcinogens estimated through the CAREX method feature basic limitations on their application to exposure assessment within epidemiology. The CAREX surveillance system lacks information concerning the use of occupational and job classifications for industries in which DEE is generated, as well as on levels of exposure, which could be used to associate the risk of health effect. Further standardization of classifications based on occupation and exposure level is recommended for an epidemiologic study when the CAREX surveillance system is further refined in respective countries. The number of workers exposed to occupational carcinogens in Canada was estimated based on CAREX projects in the EU. CAREX Canada's exposure estimates were presented for every available dimension, including industry, occupation, province, sex, and exposure level, which is a key enhancement compared with previous CAREX projects [6]. Priority was given to common occupations and industries with high DEE exposures, which contribute significantly to the results of epidemiological studies. Further refinements are possible as new exposure measurement data become available [11].

Thirdly, differences in industry structure or scale among countries should be considered when adapting the CAREX method. The industrial substructure of the Republic of Korea—one of the most industrialized countries in the world—may differ considerably from the 15 EU countries depending on the type of products or manufacturing processes used. For example, automobile, ship, and electronics manufacturing in the Republic of Korea are leading industries that are either limited or do not exist in other countries, including some countries in the EU. Exposure to DEE in automobile and ship manufacturing workplaces particularly occurs during repair or testing procedures when the operators work adjacent to or underneath an engine and where engines are running as part of the operation. With the considerable number of workers exposed to DEE, the present results warrant greater attention and further study.

In conclusion, in spite of the apparent limitations, our estimation of occupational exposure to DEE based on the CAREX method can potentially be used to assess exposure to DEE by industry, to identify high-risk groups by industry, and to set priorities for prevention-related activities. When combined with data on exposure levels and other specific exposure characteristics such as job and occupation, they can also contribute to a decrease in carcinogen exposures and thereby to the prevention of occupational cancer among exposed workers.

Conflicts of interest

No potential conflicts of interest related to this article were reported.

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