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ORIGINAL ARTICLE

Estimation of Amount of Pollutants Generated by Vehicles in Turkey Until 2030

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ABSTRACT

Air pollution is triggering and accelerating the global warming. In this study, the amount of the pollutants resulting from the vehicles is estimated in accordance with changes of the total number of vehicles in Turkey until 2030. The number of vehicles by 2030 is estimated according to the number of vehicles between 2001-2007 years. The Approximate average annual kilometers of vehicles is calculated and amount of the pollutants is also calculated by using dynamic emission factors. According to result of estimation, total number of vehicles in the years 2010-2020-2030 is 11657460, 18358290, 25294090 respectively, and the amount of total exhaust emission (CO, PM, HC, NOx, SOx) is 63, 105, and 173 million tons respectively. Total amount of pollutants in 2020 increased %66 compared with 2010 and 2030 increased %64 according to 2020. While number of vehicles increase %116, amount of pollutants is estimated to increase %174 in 2030 compared with 2010.

Key Words: *Vehicle emissions, pollutants, estimation of emissions, estimation of vehicle number.*

1. INTRODUCTION

Air pollution is a problem on which people have been focusing for centuries. Air pollution hastening as a result of unconscious usage of world energy springs has caused deaths in different regions and different times partially due to effects of geographic conditions. Moreover, respiratory tract infection, eye and skin irritation and cancer risk are some of the problems caused by air pollution on humans.

Pollutants which stem from motor vehicles especially in cities threat human's health reaching high intension. When taken into consideration these effects of the air pollution, the importance of the pollutants on human and environment that stem from vehicles like carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NO_x), particle substance (PM), sulphur (S), lead (Pb) and volatile organic compounds (VOC_s) increases [1-6].

When looking at Table 1 it is seen that highways have a part over %90 in freight and passenger transportation in Turkey [1]. In Turkey almost all of the freight and passenger transportation is made by road vehicles. As seaway and railway are still developing and cost of airway transportation is high, highway is more preferred.

Table 1. Turkey's arrival modes proportion (%) [1].

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	Highways	Railways	Seaways	Airways	Total
Ton-km	92	5	3	0	100
Passenger-km	95	3	0	2	100

As understood from all statements pollutants generated by vehicles have a great effect on human health and environment. Therefore; determining current vehicles emissions, making suggestions for future and depending on these suggestions taking measures beforehand to prevent possible problems are quite important. In this research, according to current vehicles type and number emission is estimated. Then, according to these findings change of vehicle number and depending on total number of vehicles amount of emission in Turkey until 2030 are estimated.

While motor vehicle number was 580 millions all around the world in 1990, it is estimated that motor vehicle number will reach 816 millions in 2010. Researches show that there is close relationship between income and owning vehicle [7].

Increase or reduction of the vehicle number in a region or country depend on some reasons such as changes in the socio-economic structure, population and improvement of income level in that region or country.

For instance, Konya has improved in various fields thanks to these improvements its socio-economic structure has changed and its population has increased substantially. With this increase motor vehicle number has increased, too [8].

When taken into consideration this information in order to estimate number of vehicles in the future, number of vehicles between 2001–2007 has been received. In Table 2 number of vehicles between 2001–2007 is shown. When motorcycles are disregard, almost all of the vehicles in Turkey are automobiles (auto), light duty trucks (Lts), heavy duty trucks (Hts), minibuses (Mbs) and buses. Therefore, in this study for pollutant estimation these vehicle types are taken account.

2. METHOD

To make estimations and determine vehicle emissions, current vehicle number should be known and how vehicle number will change in the future should be determined. Determining vehicle number in the future is possible to research how vehicle number has changed up to now. Therefore; it is made use of the number of vehicles in Turkey between 2001-2007 years.

In Table 2 data of Turkish Statistical Institute has been fitted for each vehicle type. Thanks to this, various degree polynomials have been used for estimation of vehicle number in the future.

Table 2. Number of road motor vehicles by type [9].

Year	Total	Automobile	Minibus	Bus	Light Truck	Heavy Truck
2001	6 123 158	4 534 803	239 381	119 306	833 175	396 493
2002	6 236 343	4 600 140	241 700	120 097	875 381	399 025
2003	6 447 728	4 700 343	245 394	123 500	973 457	405 034
2004	7 779 393	5 400 440	318 954	152 712	1 259 867	647 420
2005	8 426 660	5 772 745	338 539	163 390	1 475 057	676 929
2006	9 079 623	6 140 992	357 523	175 949	1 695 624	709 535
2007	9 653 546	6 472 156	372 601	189 128	1 890 459	729 202

Determination number of vehicles is not sufficient to estimate vehicle emissions. Depending on the fuel type used in vehicles amount of pollutants vary. To make a correct acceptation, fuel types of specified vehicles should be determined correctly.

According to Table 3 while %81.35 of vehicles was gasoline vehicles in 2001this proportion reduced to %41.29 in 2007. Moreover, while %18.65 of vehicles was diesel vehicles this proportion increased %35.85 in 2007. Also while there weren't any vehicles with LPG in 2001, in 2007 %19.5 of vehicles used LPG[9]. According to this information, in the pollutant estimation that is made until 2030 while all of the vehicle types such as minibuses, buses, heavy duty trucks and light duty trucks are accepted as diesel, %35 of automobiles are accepted as gasoline vehicles, %25 of automobiles LPG vehicles, and %40 of automobiles diesel vehicles.

Table 3. Number of road motor vehicles by type of fuel used [9].

Year	Total	Gasoline	%	Diesel	%	LPG	%
2001	6 123 158	4 981 422	81.35	1 141 736	18,65	-	
2002	6 236 343	5 044 259	80.88	1 192 084	19.12	-	
2003	6 447 728	5 130 400	79.57	1 317 328	20.43	-	
2004	7 779 393	4 366 622	56.13	2 198 490	28.26	818 127	10.5
2005	8 108 863	4 175 709	51.49	2 635 509	35.5	1 297 542	16.0
2006	8 812 189	4 122 134	46.77	3 121 797	35.42	1 568 158	17.8
2007	9 653 546	3 986 145	41.29	3 557 981	36.85	1 877 604	19.5

While determining amount of the pollutants the other important parameter is emission factor. In computation of amount of the pollutants depending on fuel consumption, type and number of vehicles, various emission factors are used. Emission factors depend on type and compound of the fuel and ignition system. Therefore, it can be said that emission factors depend on technological developments. Emission factors that are massive should be determined taking into account system activity [10]. In Table 4 emission factors according to fuel types are shown [11].

Various researches are done to determine emission factors [12-16]. Besides, researches aim not only to evaluate emissions factors today's values but also to find out what their values will be in the future.

Zhang and his friends have determined emission factors depending on types of vehicle for gasoline and diesel fuel and developing a dynamic model on emissions generated by vehicles. In the study, lots of parameters are taken into account such as, fuel consumption, average vehicles kilometers traveled in a year and CO, NO_x, CO_2, PM and HC pollutants emission factors are determined until 2030 but for SO_x they make no suggestion. Emission factors that Zhang and his friends estimated for 2004–2030 years are shown in Table 5 and Table 6 [17].

Table 4. Pollutant factors by type of fuel (kg/ton) [11].

Compound	Pollutants factors by type of fuel								
	LPG/ NG	Gasoline	Gasoil	Diesel	Fuel-Oil	Coal	Lignite	Wood	Turd
CO	0.0031	375.30	10.0	8.83	0.252	25.0	25.0	25.0	25.0
HC	0.000	32.61	50.0	20.02	0.4	5.0	5.0	5.0	5.0
NOx	0.908	18.42	25.0	31.00	9.08	4.0	4.0	5.5	5.5
PM	0.149	1.96	15.0	16.19	1.01	150.0	200.0	7.0	7.0
SOx	0.0031	1.47	2.5	5.88	60.0	16.0	120.0	2.0	2.0

Table 5. Pollutant factors for 2004(kg/ton) [17].

Pollutants	Automobile		Bus		Light Duty Truck		Heavy Duty Truck	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
CO	202.81	15.84	382.175	27.476	233.256	17.767	347.472	38.604
PM	0.143	0.57	0.293	1.348	0.122	0.732	0.318	1.441
NOx	15.135	11.24	24.797	57.744	19.608	12.593	22.878	58.627
CO_2	2996.82	2852.84	2675.202	2804.069	2926.580	2841.22	2724.851	2802.813
HC	12.86	3.36	25.243	7.755	19.878	6.058	26.797	7.93

Table 6. Pollutant factors for 2030 (kg/ton) [17].

Pollutant	Automobile		Bus		Light duty truck		Heavy duty truck	
	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
CO	133.054	8.849	168.635	11.686	120.675	9.511	131.108	12.127
PM	0.062	0.247	0.867	0.351	0.076	0.245	0.091	0.360
NOx	2.216	5.895	7.229	15.77	2.162	6.383	7.635	18.023
CO_2	3138.121	2872.046	3058.283	2855.639	2728.756	2870.860	3120.702	2854.651
HC	2.94	1	10.445	4.534	2.702	0.825	9.81	4.604

As this study includes estimation for future emission factors and many parameters, Zhang and his friends' emission factors are used. However, as Zhang and his friends made no suggestion for SO_x emission factors, SO_x emission factors in Table 4 are used.

Other necessary datas to estimate amount of pollutants are average vehicles kilometers traveled, and fuel consumption. Vehicle travelling kilometers were determined taking 100 sample's average for each vehicle model. Average kilometers travel of automobile, bus, minibus, light duty truck, heavy duty truck are determined as 15000, 60000, 36000, 25000 and 40000 km respectively. According to the findings and evaluations, fuel consumption of automobile is accepted as for the vehicles with gasoline 8 lt/100km, for the vehicles with diesel 6lt/100km and for the vehicles with LPG 11 lt/100km. Average fuel consumption for bus, heavy duty truck, light duty truck and minibus that all of them are accepted as diesel is 20, 25, 13, 13 lt/100km respectively.

According to data of Turkish Petroleum Industry Association (TPIA) 2540000 tons gasoline, 2007000 tons LPG and 12957000 tons diesel were consumed in 2007 [18]. However, when taken into account number of vehicles in 2007, fuel consumption and average vehicles kilometers traveled the fuel consumption were 2011546 tons gasoline, 1858857 tons LPG, 117411337 tons diesel. The reason of the difference between two calculations can be due to the fuel used by the other vehicles such as motorcycle and jeep. Additionally, another reason of this difference is the unregistered vehicles and the fuel that is used in other various fixed facilities. When taken into account annual fuel consumption, the accuracy of acceptations is supported by TPIA's data. With respect to all information, a package programme is prepared programming with DELPHI and amount of emissions are determined.

RESULTS AND DISCUSSION

In Figure 1 it is seen that number of automobiles are fitted with a fourth degree polynomial. Here correlation coefficient that is 0.978 takes a value close to 1 and this shows that accuracy coefficient of estimation process is large. So the number of vehicles growing trend in the past years can be transferred to the next years accurately. While the number of automobiles is 7.525 million in 2010 in the years 2015, 2020, 2025, 2030, the number of automobiles is estimated as, 93.503, 11.202, 13.081, 14.987 million respectively.

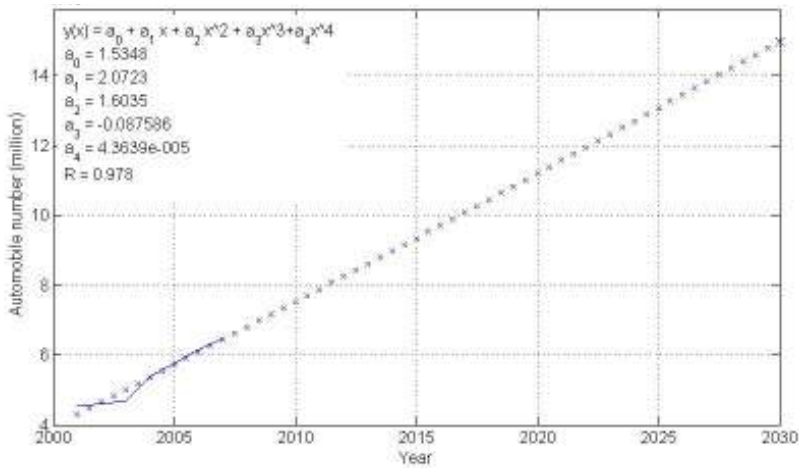

Figure 1. Approximative distribution of the number of automobiles according to years.

In Figure 2 it is seen that the number of minibuses have been fitted with a fourth degree polynomial. Generally it is sufficient that various curves and scatters are fitted with a third degree polynomial. However, it is appropriate to use higher degree polynomials to make

fitting process more sensitive. Here correlation coefficient is found as 0.95741. Accordingly, while the number of minibuses is, 459260 in 2010, in the years 2015, 2020, 2025, 2030 the number of minibuses is estimated as 591990, 726710, 863420 and 1002200 respectively.

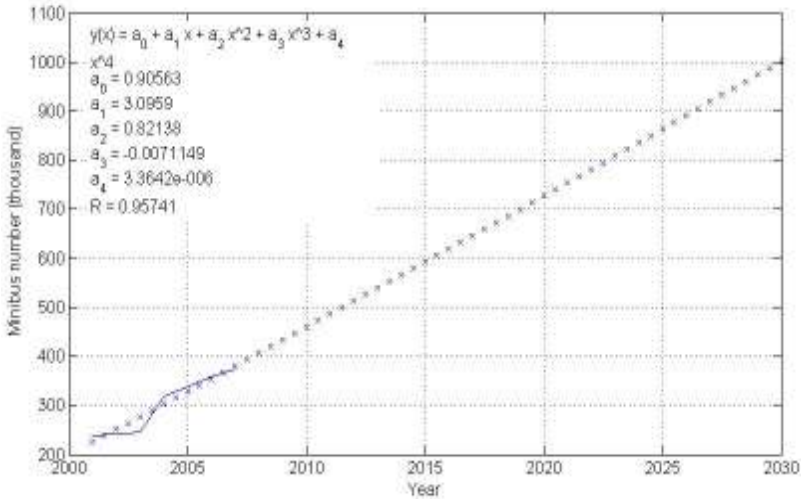

Figure 2. Approximate distribution of the number of minibuses according to years.

Number of buses is fitted to. Correlation coefficient's being 0.97262 indicates that strong relationship. Accordingly, while number of buses is 262220 in 2010, in the years 2015, 2020, 2025, 2030 number of buses is estimated as 292400, 359580, 427770, 496990 respectively. However, when taken into account development of railway network and railway transportation and planning of airline transportation cost fall, it is estimated that the number of buses will increase in less and determined number of buses may be less.

Similarly, for the number of heavy duty trucks and light duty trucks fitting process has been performed. While number of light duty trucks is 2439700 in 2010, in the years 2015, 2020, 2025, 2030 the number of light duty trucks is estimated as 3413300, 4401200, 5403700, 6420800 respectively. In the fitting process, correlation coefficient has been found as 0.98464. For the years 2010, 2015, 2020, 2025, 2030 the number of heavy duty trucks has been determined as 971180, 1317480, 1668.800, 2025400, 2.387.100 respectively and correlation coefficient of fitting process has been found as 0.92662. In our country where road transportation is over %90, the number of light duty trucks and heavy duty trucks is increasing rapidly. So this situation may cause big problems in terms of air pollution, traffic pattern and traffic noise level.

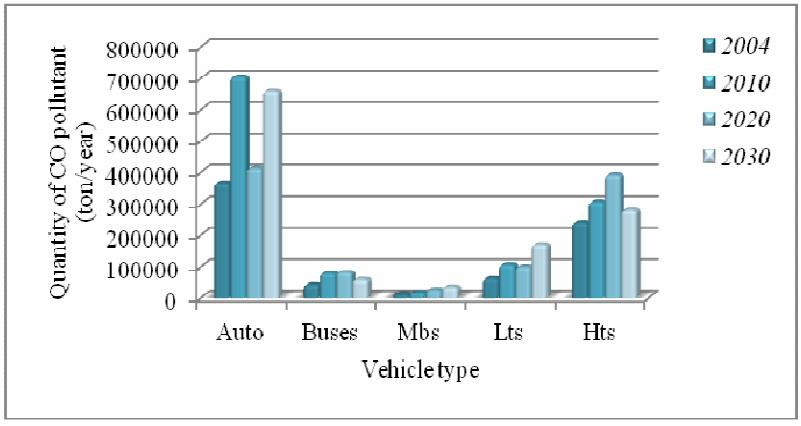

Figure 3. Approximate change of amount of CO from vehicles.

In Figure 3 amount of CO generated from vehicles between 2004–2030 is seen. While amount of CO pollutant from automobiles reaches highest level with 704.656 tons in 2010, it has been estimated to go down to 660.830 tons in 2030. This decline because of emission factors that including the legal restrictions. Depending on the rapid increase of number of minibuses and light heavy trucks, amount of CO pollutant increase regularly. Amount of CO from light duty trucks is 62563, 107057, 99886, 170685 in 2004, 2010, 2020, 2030 respectively. While amount of CO from buses reaches highest level with 82752 tons in 2020, it has been estimated to go down to 59936 tons. In this decline, developments of railway and airway transportation in passenger transport are considered to be effective. Similarly, while amount of CO from heavy duty trucks reaches highest level with 392662 in 2020, it has been estimated to go down to 280075 in 2030. While the total amount of CO is 1.214

million tons in 2010, it is estimated that it will reduce to 1.207 million tons cutting down %0.58 in 2030.

The engine technology development helps increase of productivity of combustion, due to this fact more reduce in CO emission may be registered.

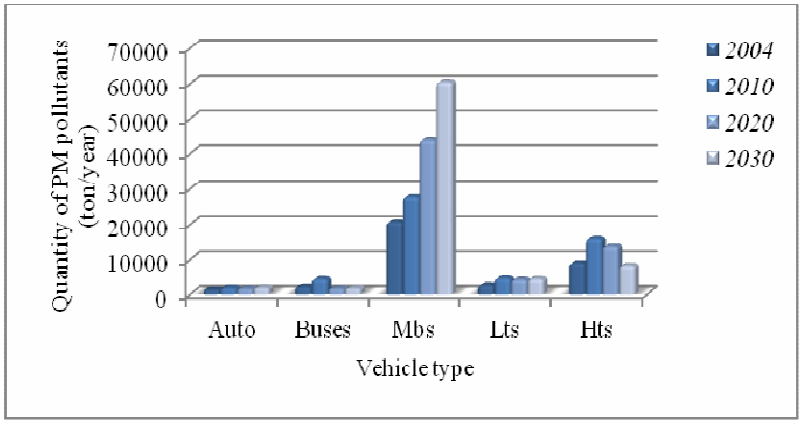

Figure 4. Approximate change of amount of HC from vehicles.

In Figure 4 amount of HC from vehicles between 2004–2030 can be seen. Hydrocarbons in vehicles are produced in cooler regions through cylinder walls. While amount of HC from automobiles is 29103 in 2010, it goes down to 18334 in 2030. Amount of HC from minibuses and heavy duty trucks are increasing regularly. While total amount of HC from vehicles is 149034 tons in 2010, it is estimated to reach 194005 tons increasing %30 in 2030.

In Figure 5 the changes in the amount of PM pollutants from vehicles are viewed. The most striking points in the graphic are PM pollutants from minibuses are the most and in 2030 compared with 2004 more than double increase are performed.

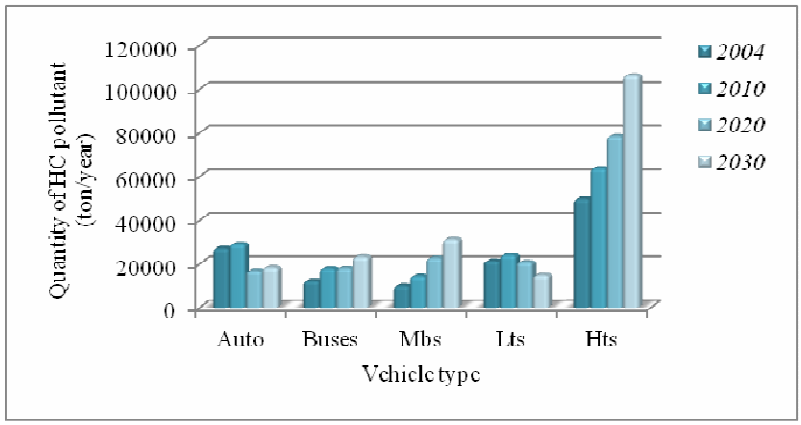

Figure 5. Approximate change of amount of PM from vehicles.

Except for extreme productive mixtures, PM emission is little as much as possible. However, in terms of PM emission, the diesel engine is about 20 times more efficient than a petrol engine. Depending on lambda (λ), carbon particles produced in diesel engines causes PM emissions in cases of inefficient time for combustion. These particles consist of lambda, smut and inorganic substances [19, 20].

Extreme loading is applied to diesel engines working with excess of air. While passing from low speed to high one in engines which turbochargers are used in, required amount of the air for the fuel being sprayed into cylinder is not able to supply due to insufficient growing of turbo rotation. And this causes the engine to be worked in low lambda, namely in more extreme mixtures. Due to the insufficient oxygen for the fuel molecules, combustion is unable to be completed and then PM emissions occur. This situation occurs much more in places with local dense traffic. Minibuses use much of their daily movement in local areas. Consequently, PM pollution from minibuses is much more than any vehicle. Amount of PM that is 54256 tons in 2010 is estimated to reach 76966 tons increasing %41 in 2030.

In Figure 6, we can see change in rates of NO_x pollution from vehicles in between 2004 and 2030. There is little difference in amount of NO_x pollution of automobiles between 2004 and 2030. Despite increase in number of automobiles, it's possible to keep the amount of NO_x at the same level as a result of increase of sales of LPG and restrictions. While the amount of NO_x from automobiles is 45329 tons in 2004, this reduces into 40818 tons in year of 2030. Amount of NO_x from minibuses has a

steady increase as a result of rapid increase in sales of minibuses and their use in local traffic. This increase can be seen also in amount of NO_x from light duty trucks due to the increase in sales. While the amount of NO_x from minibuses is 39.795 tons in 2004, this goes up to 125.043 tons in year of 2030. Also while the amount of NO_x from light duty trucks is 44344 tons, this goes up to 114550 tons in year of 2030. It is expected that the number of light duty trucks and buses will increase under the control and decrease use of them owing to decreasing importance of them in transportation.

Due to this fact, amount of NO_x pollution from buses reduces and the one from light duty trucks increases a little. While the amount of NO_x from buses and heavy duty trucks are 131354 tons and 465767 tons in year of 2010 respectively, it is estimated that this rates will go down to 80883 tons and 416244 tons in year

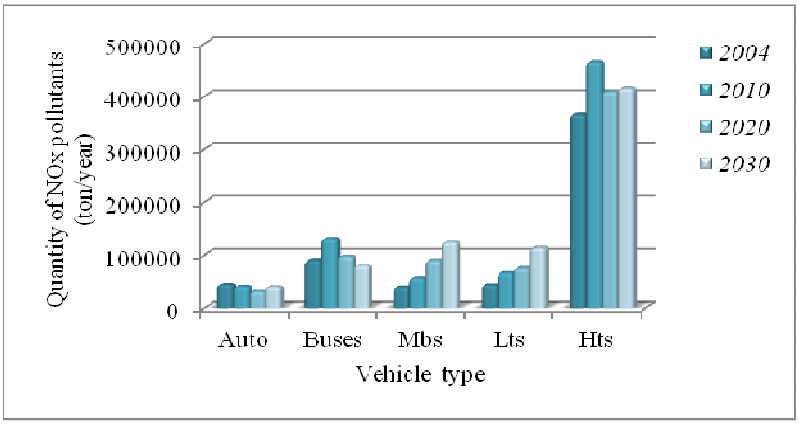

Figure 6. Approximate change of the amount for NO_x pollution from vehicles.

In Figure 7, we can see change in rates of SO_x pollution from vehicles in between 2004 and 2030. While determining amount of SO_x pollution, stable pollution factor in Table 4 is used for the fact that pollution factor being used does not place in studies of Zhang and his friends, as told before. As a result of this, it is observed that the change of SO_x ratio has gone up proportionally with the increase in number of vehicles. As seen in the diagram; the more number of vehicles increases, the more amounts of SO_x increases.

Determining SO_x pollution factor for the year of 2030, it is suggested that amount of SO_x would be decrease partially, if restrictions and improvements in fuel consumption are noticed. Another reason for the increase of SO_x from the automobiles can be seen as

the more and more increase in number of cars with diesel fuel. With reference to the diagram, amount of SO_x from automobiles, buses, minibuses, light duty trucks and heavy duty trucks is in order about 34140, 30158, 323717, 55991 and 135799 tons.

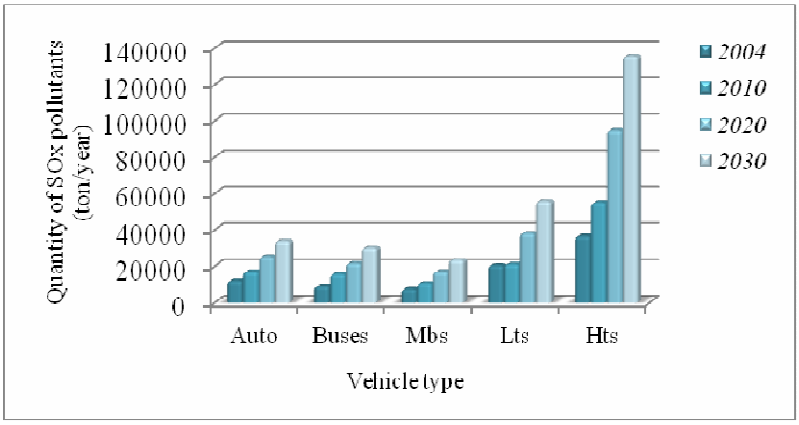

Figure 7. Approximate change of the amount for SO_x pollution from vehicles.

CO_2 is one of the pollutants, which has Greenhouse gas effect and great importance for the future of the world. Anyway, it is also a kind of pollutant which can be made harmless with natural methods. CO_2 is an inevitable pollutant producing from vehicles. An amount of CO_2 comes out as a result of combustion including cases of a complete one [21]. As seen in figure 9, amount of carbon dioxide increases rapidly as well as number of vehicles increases. Due to the fact that large engines consume much more air, they produce much more CO_2 after combustion. According to figure 8, it is light duty truck and heavy duty truck which produces the most amount of carbon dioxide among vehicles. While the amount of CO_2 produced by light duty trucks is 10004868 tons in 2004, this ratio goes up to 51520844 tons in year of 2030 as a result of rapid increase in number of light duty trucks. As another value; while the amount of CO_2 produced by trucks is 17556227 tons in 2004, this goes up to

65928714 tons in 2030. Providing enough forest areas and plant cover, it is possible to recycle carbon dioxide as a part of the ecological balance. Lots of restrictions have been applied to CO_2 outflow, however those cannot remove all of it; therefore enhancing forest areas is the only suitable method for the recycling. While amount of CO_2 is 61.434 tons in 2010, this amount is estimated to reach 171.35 tons increasing %179 in 2030.

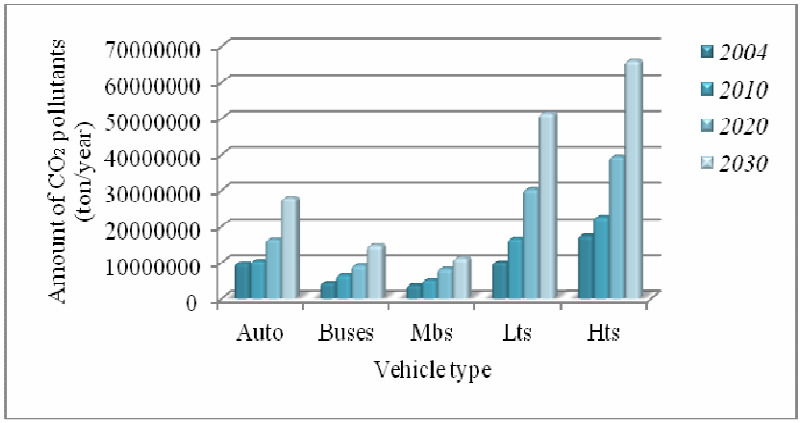

Figure 8. Approximate changes in total amount of CO_2 pollution in between 2004-2030.

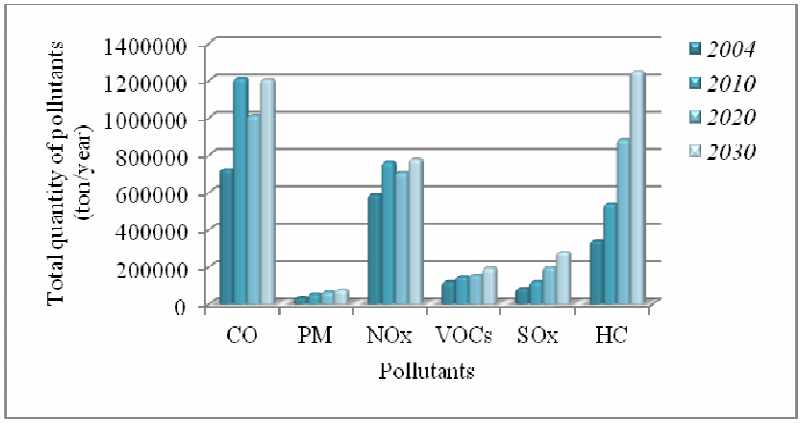

Figure 9. Approximate change in amount of total pollution produced by vehicles.

In Figure 9 cumulative overalls of pollutions from vehicles according to kinds of vehicles, can be viewed. Taken a look at the diagram, it can be seen that there is no mentionable decrease in ratio of pollutants despite even using emission factors that includes prudential decrease in fuel consumption and emission limits, this is because of the fact that there has been a rapid increase in number of vehicles. While total amount of pollutants such as CO, HC, PM, NO_x and SO_x is 1897888 tons in 2010, this ratio rises to 3785336 tons in 2030.

CONCLUSION

Amount of pollution generated by vehicles between the years 2004 and 2030 in Turkey, has been estimated by using programs MATLAB and DELPHI, and also by considering prudential emission factors into account.

When taken into consideration the data it is seen that number of vehicles increases rapidly. It is estimated that number of vehicles 11.657 million in 2010 will reach 25.294 million increasing %116 in 2030. Development of socio-economic structure may be a factor in this increase. Besides, decrease of cost and increase of competition may be a factor in the increase of number of vehicles. If number of vehicles increase normally, the number of vehicles will reach 15 million in 2010 in Turkey. In case of the increase of number of vehicles per capita 0.25 and 0.40 respectively depending on population in the next years, number of vehicles is estimated to increase 19 and 30 million [22]. With the increase of population, number of vehicles is expected to increase rapidly. Thus, amount of population from vehicles will increase. Measures should be taken to prevent rapid increase of number of vehicles. Directing people to public transport may be a solution.

Although emission factors Zhang et al. achieved prudentially, has been used in process of estimating; a tendency on a decrease or keeping o a stable level could not be got seen. The reason of this situation is the extreme increase especially in number of automobiles as a result of increasing income level and socio-economic position as well as improvements in fuel consumption and various alternative transportation fields. Increase in fuel having consumed for a whole year as well as increase in number of cars, causes to increase amount of pollution.

Alternative fuels must be made common to use instead of fuel of petroleum origin seen as the main source for

pollution [23, 24]. Moreover, alternative energy resources such as fuel cell, hybrid electric vehicles, solar power, wind power, underground hot water resources must be given much more importance and attention.

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