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Economic and Environmental Effects of Treadwear Index in Vehicle Tires

Emre ARABACI[1], Bayram KILIÇ[2], Recep Çağrı ORMAN[3*]

[1]Automotive Technology Department, Vocational School of Technical Sciences, Burdur Mehmet Akif Ersoy University, Burdur, Turkey
[2]Hybrid and Electric Vehicles Department, Vocational School of Technical Sciences, Burdur Mehmet Akif Ersoy University, Burdur, Turkey
[3]Department of Automotive Technology, Tusaş-Kazan Vocational School, Gazi University, Ankara, Turkey
recepcagriorman@gmail.com

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Abstract: The only component in contact with the ground is the vehicle wheels. Tires used in vehicle wheels are quite diverse on the market. Although the tire tread pattern and brand are used as an important parameter in the purchase of vehicle tires, the tire treadwear index, which is an indicator of tire life, is unfortunately ignored. In this study, the economic and environmental effects of the tire treadwear index were examined using the price and tire treadwear index values for 7 different manufacturers, 20 different models and 3 different dimensions for these tire models. Every 100 tire treadwear index value indicates 32000 km tire usage life and tire sales prices have not changed according to tire treadwear index. However, considering the number of tire changes during the economic usage period of the vehicle (about 10 years≅160000 km), it is determined that a saving of up to 70% can be achieved. The same is true for reducing particulate matter emissions (or CO_2 equivalent emissions) caused by tire wear. The results of the study are especially important and interesting for vehicle manufacturers and tire dealers. However, this study provided very practical information, especially in terms of assessing the economic and environmental impacts of vehicle owners' tire choice.

Keywords: tire wear, carbon footprint, non-exhaust vehicle emission

Taşıt Lastiklerinde Diş Aşınma İndeksinin Ekonomik ve Çevresel Etkileri

Öz: Yer ile taşıtın temas halinde olduğu tek komponent taşıt tekerlekleridir. Taşıt tekerleklerinde kullanılan lastikler piyasada oldukça çeşitlidir. Taşıt lastiklerinin satın alımında, lastik sırt deseni ve marka tüketiciler tarafından önemli bir parametre olarak kullanılmasına rağmen, lastik ömrünün göstergesi olan lastik diş aşınma indeksi maalesef göz ardı edilmektedir. Yapılan bu çalışmada 7 farklı lastik üreticisinin, 20 farklı lastik modeli ve bu lastik modellerine ait 3 farklı lastik boyutu için fiyat ve lastik diş aşınma indeksi değerleri kullanılarak, lastik diş aşınma indeksinin ekonomik ve çevresel olarak etkileri incelenmiştir. Her 100 lastik diş aşınma indeksi değeri 32000 km'lik lastik ömrünü işaret etmektedir ve lastik diş aşınma indeksine göre lastik satış fiyatlarının değişmediği belirlenmiştir. Ancak taşıtın ekonomik kullanım süresi boyunca (yaklaşık 10 yıl≅160000 km) lastik değişim sayısı göz önünde bulundurulduğunda %70'e kadar bir tasarruf sağlanabileceği belirlenmiştir. Aynı durum lastik aşınmasından kaynaklanan partikül madde emisyonunun (veya CO_2 eşdeğeri emisyon) azaltılması için de geçerlidir. Yapılan çalışma sonuçları özellikle taşıt üreticileri ve lastik satıcıları için önemli ve ilgi çekicidir. Bununla birlikte, bu çalışma özellikle taşıt sahiplerinin lastik seçiminin ekonomik ve çevresel etkilerinin değerlendirilmesi bakımından oldukça pratik bilgiler sunmuştur.

Anahtar kelimeler: lastik aşınması, karbon ayak izi, egzoz dışı taşıt emisyonu

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1. Introduction

One of the greatest innovations in humankind's life, the wheel was invented in 3500 BC. While wood was used for wheel construction, leather was used as a soft material later. Today, the basic wheel material is rubber [1, 2].

The wheels used in today's vehicles consist of two basic parts, tire, and rim. Pneumatic tires are widely preferred in vehicles. The only interaction between the road and the vehicle is through tires. There are several standards for sizing tires and wheels. However, there are also standards for specifying the characteristics of tires with different properties or special purposes. These standard expressions, written on the side of a tire, offer a lot of information about the tire [1, 3].

When the tires are examined structurally, it is seen that they do not have a smooth surface. There are shapes of various grooves on the tire surface and these shapes are called tire print. The tire print (or tire tread pattern) provides specific properties to the tire, and thanks to the tire print, it is necessary for many features such as expelling water from the beneath of the tire, better traction the tire to the road surface [2, 3].

Emissions from vehicles are not just emissions from the exhaust. Vehicles also have non-exhaust emissions. One of the most important is the particle matter emission caused by tire wear. Tires operating in different road and climate conditions are in constant contact with the road and therefore wear constantly during the movement of the vehicle. The chemical structure of the tire can vary depending on the tire's usage conditions and purpose of usage. However, in general, the wearing surface of the tire consists mainly of rubber. Worn rubber particles are emitted to the atmosphere, and these are one of the non-exhaust vehicle emission sources. Although tire wear is a parameter that depends on vehicle, road, load and driver characteristics, tire wear duration can be determined for standard test conditions. Although tire wear, driving style, road quality, balance, alignment, speed, load, and pressure are parameters depending on vehicle, road, load and driver characteristics, tire wear time can be determined for standard test conditions. Many parameters that affect tire tread wear, but these parameters are generally not overlooked by drivers. Driving style or, in other words, driving habits are a parameter that cannot be measured for tire wear but has very clear results. However, these driving habits can be checked and the wrong habits can be replaced by the right ones. This should be considered not only for tire wear but also for driving safety. Road quality is an uncontrollable factor for the driver. Alignment (vehicle geometry adjustment) is within the scope of vehicle maintenance and is an important parameter affecting tire wear. Tire pressure, like other parameters, is a parameter that directly affects tire wear. Tire pressure varies depending on the load in-vehicle use and it is recommended to check frequently [2-8].

Previous studies on tire wear are also available. İsmailoğlu et.al. examined the effect of the ground on tire wear. In this study, for the effects of various road (asphalt and concrete), load (10 to 30 kg) and tire air pressure conditions (28 to 32 psi) on the tire wear, the amount of particle matter caused by wear was observed thanks to the skid test set. With the increase of tire pressure, it was determined that the wear zone slides towards the middle of the tire, and the tire wear in the concrete ground is higher than in the asphalt ground. [9]. On the other hand, Altın et al. determined the tread depth and usage times of the tires used in the vehicles and calculated the amount of particles matter. In this study, it was reported that 1.479 kg of tire waste was discarded in solid form throughout the life of the tire [10]. Although these studies in the literature [9, 10] were based on experimental methods, the characteristics of the tires selected for the experiment were ignored. Grigoratos et al. studied experimentally the relationship between treadwear index and mass loss due to tire wear [11]. In this study, the amount of particle matter of different manufacturers with different treadwear index in a certain period was determined experimentally [11].

In this study, unlike previous studies, the wear values of 3 different sizes of tires from different manufacturers were calculated according to the treadwear index values and environmental and economic results were obtained. However, the particle resulting from wear was calculated as the carbon dioxide equivalent. For this, a tire wear scenario has been created first and calculations have been made for tires with different characteristics according to this scenario, and the results obtained have been presented and discussed.

2. Tire Wear Scenario

To create a tire wear scenario, it is necessary to know the properties of the tire and make some theoretical assumptions. Tires are produced to certain standards. The tire properties are located on the sidewall of the tire (Figure 1). The information contained in the tire is often not explicitly expressed. Instead, there are some accepted standard impressions. For example, information such as tire diameter, date of manufacture, wear, maximum load, maximum speed have not been written publicly and various indices, ratios, and abbreviations have been used for this information.

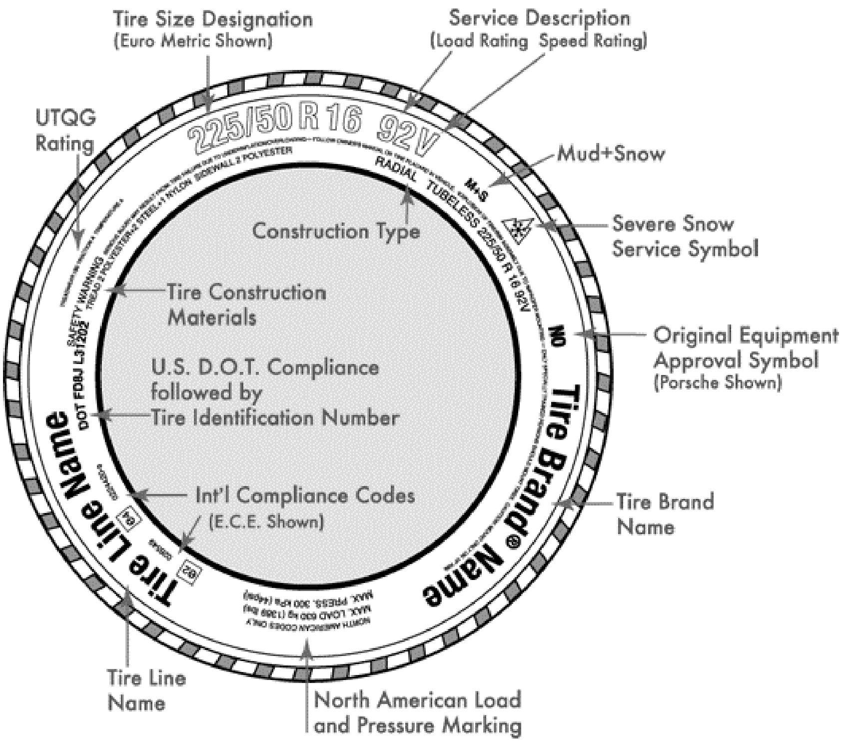

Figure 1. Information on the tire sidewall [12]

In Figure 1, "Tire Size Designation", tire width (w_T, mm), aspect ratio (r_A, %) and rim diameter (D_R, inch) format are shown. Eq. 1 and Eq. 2 are used for the calculation of tire diameter (D_T, m) and tire height (h_T, mm).

$$h_T = w_T r_A \quad (1)$$

$$D_T = [25.4 D_R + 2(h_T)]10^{-3} \quad (2)$$

The standard tire tread depth ($d_{TT,max}$) of a vehicle tire is 8 mm and although the legal limit ($d_{TT,min}$) is 1.6 mm, the safety limit ($d_{TT,safety}$) is considered as 3 mm. There are tire treadwear indicators on the tires that represent 1.6 mm tread depth as in figure 2. Tire wear is assumed to be 100% when the tread depth is 1.6 mm.

As the tire tread depth decreases, the vehicle's stopping distance on wet ground increases. Figure 3 shows the stopping distance of a vehicle driving at a speed of 80 km.h^{-1} depending on tire wear. When the tire tread depth is 3 mm (78% worn), which is the safety limit, the vehicle appears to be standing at a distance of approximately 35% longer due to tire wear.

Figure 2. Tire treadwear indicators [13, 14]

However, when the tire tread depth is the legal limit of 1.6 mm (100% worn), the vehicle can stand approximately 56% longer.

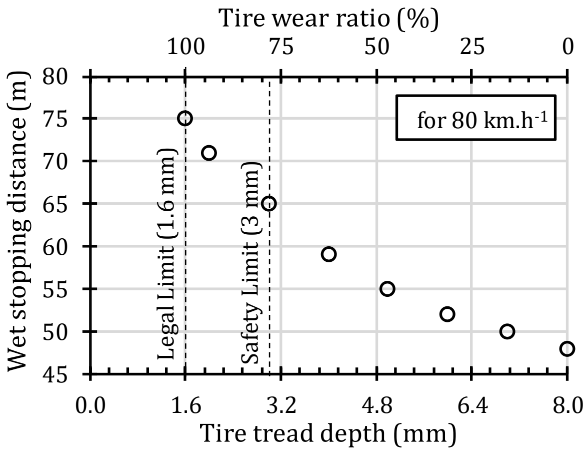

Figure 3. Effect of tire tread depth on wet stopping distance

Tire wear rate (r_{TW}, mm) is expressed as in Eq. 3.

$$r_{TW} = 100\left(\frac{d_{TT,max} - d_{TT}}{d_{TT,max} - d_{TT,min}}\right) \cong 125 - 15.625 d_{TT} \quad (3)$$

Accordingly, the diameter of a worn tire ($D_{T,worn}$, m) is expressed as in Eq. 4.

$$D_{T,worn} = \left[25.4 D_R + 2\left(h_T - d_{TT}(100 - r_{TW})\right)\right]10^{-3} \quad (4)$$

Tire surface area (A_T, m) decreases as the tire wears. As a simple calculation, when the tread depth decreases from 8 mm to 1.6 mm, the wheel diameter decreases by 12.8 mm. This means that the circumference of the tire is reduced by approximately 40 mm. Therefore, the average wheel surface area ($A_{T,avg}$) should be determined. However, tire width (w_T) and tire print width (w_{TT}) where the tire touches the ground are different concepts (Figure 4). According to this information, the average tire surface area can be calculated as follows.

$$A_{T,avg} = \left(\pi D_{T,avg} w_{TT}\right)10^{-3} \quad (5)$$

$$D_{T,avg} = 0.5\left(D_{T,max} + D_{T,worn}\right) \quad (6)$$

$$w_{TT} \approx 0.9w_T \approx w_{RP} \quad (7)$$

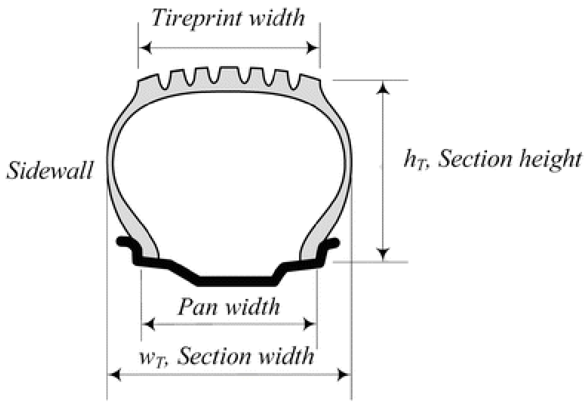

Figure 4. Tire print width [2]

It is valid if the $A_{T,avg}$ wheel surface calculated here is smooth. Tire print has a unique pattern. With these patterns that the manufacturers create on the tire, it provides many features to the tire (Figure 5).

Figure 5. The pattern of tire print [15]

Generally, there are lugs (also called blocks or ribs), voids (also called grooves) and sipes on the tire. The area of the tire that touches the ground is expressed as the lug area ($A_{T,lug}$) and is calculated as follows.

$$A_{T,avg} = A_{T,lug} + A_{T,void} \quad (8)$$

$$A_{T,lug} \approx 0.846A_{T,avg} \quad (9)$$

The following equations are used to calculate the volume and mass worn from the tire.

$$V_{TW} \cong (A_{T,lug}d_{TT}r_{TW})10^{-3} \quad (10)$$

$$m_{TW} = \rho_{rubber}V_{TW} \quad (11)$$

Here m_{TW} is the amount of particulate matter the tire has emitted into the atmosphere due to wear throughout its life.

The main ingredient of the tire is rubber and is chemically expressed as C_5H_8. If all the wear part of the tire is considered to be rubber, the emission equivalent of CO_2 (CO2e, kg) can be calculated as follows.

$$\text{CO2e} \approx 3.235m_{TW} \quad (12)$$

The equations presented so far are the expression of the wear of a tire, infinite time. However, the tires are used in a finite time and replaced with a new one. In general, a tire has a shelf life of 10 years from the date of manufacture (this information must be on the tire's sidewall) [16-18]. However, there is information called the treadwear index (I_{TW}) (or UTQG- Uniform Tire Quality

Grading) on the tire sidewall. High I_{TW} means that tire life is high. Practically, I_{TW} 100 means that the tire can be used 32000 km (Figure 6) and can be formulated as follows.

$$s_{TL} \approx 320 I_{TW} \quad (13)$$

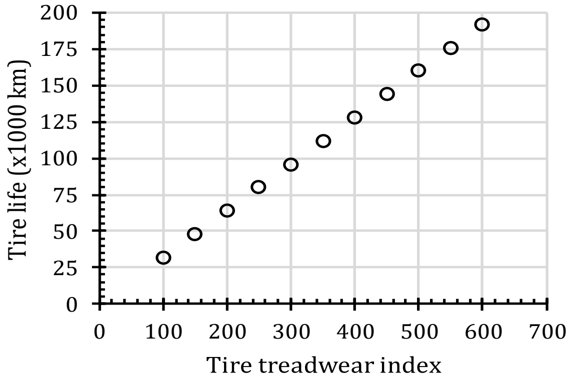

Figure 6. Tire life

Thanks to the equations presented here, how many times a vehicle has to be replaced during a certain period of use can be calculated using the tire treadwear index, and the environmental effect of this vehicle can be determined during this period of use.

3. Numerical Analysis and Results

Tires can have different tire treadwear index and the tire treadwear index is independent of manufacturer and tire size. However, tire manufacturers have the same treadwear index of all sizes of a particular tire model (there are some exceptions).

Table 1. Properties of tires used for numerical analysis

No	Manufacturer	Model	Treadwear	Tire Prices (US$)		
				195/65R15	205/55R16	225/45R17
1	1	11	200	50.00	57.17	70.33
2		12	320	50.67	59.50	82.50
3		13	280	63.83	70.00	91.50
4		14	460	68.67	87.50	76.67
5	2	21	280	76.67	90.00	99.83
6		22	360	50.00	56.67	80.00
7		23	560	95.67	105.33	126.83
8	3	31	560	41.83	47.00	60.67
9		32	340	43.33	53.50	63.17
10	4	41	420	49.00	70.17	105.00
11		42	500	55.83	73.33	132.83
12		43	220	64.17	92.33	112.67
13		44	140	68.33	86.67	100.00
14	5	51	300	42.50	54.00	96.67
15		52	400	54.83	59.83	71.33
16		53	440	58.17	92.83	101.17
17	6	61	280	43.83	66.83	85.17
18	7	71	600	61.17	70.67	80.67
19		72	400	56.50	66.50	75.33
20		73	500	58.83	66.33	100.50

For this study, tire treadwear index values and sales prices for 20 different models and 3 different tire sizes of 7 different tire manufacturers were obtained and a numerical study was made using the equations above. The purpose of the study is not to show that any manufacturer is good or bad. For this reason, the manufacturers are numbered randomly and the reference is not intentionally specified (Table 1).

In the study, the tire size 195/65R15 was considered as the reference, and tire sizes with the rim diameter of 16 inches and 17 inches were determined to be equivalent to this reference tire. The equivalent tire size is determined so that the diameter (or circumference) of the reference tire is the same. However, although the diameters of these selected tires are approximately the same (±0.4%), the tire widths are different.

3.1. Economic Effect

The change of tire treadwear index values and tire prices according to the manufacturers is as in figure 7. Accordingly, the tire treadwear index has a wide range for all manufacturers' tires (Figure 7, left). Besides, it is observed that the tire treadwear index does not affect the tire price (Figure 7, right).

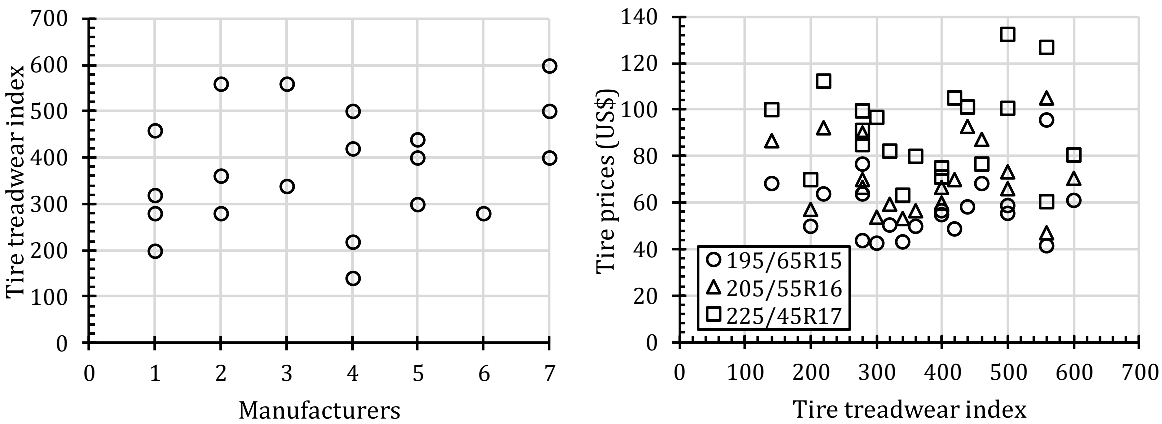

Figure 7. Change of treadwear index values (left) and prices (right)

In general, when the use of a vehicle is considered to be 16000 km/year on average, it can be said that 160000 km will be used for the 10-year economic life of the vehicle. The number of tire renewals in these 10 years varies according to the treadwear index for legal limit (1.6 mm tread depth or 100% wear) and safety limit (3 mm tread depth or 78% wear) as in Figure 8.

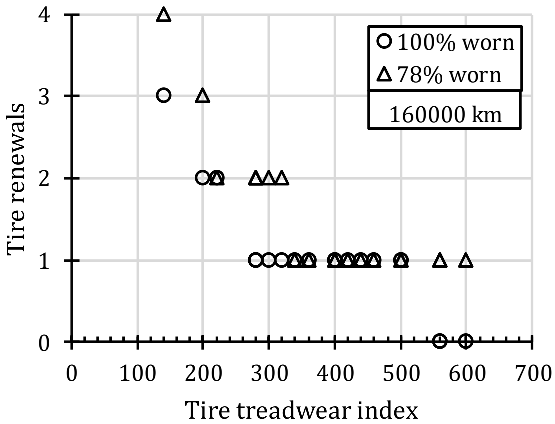

Figure 8. Tire renewal change depending on treadwear index

According to Figure 8, assuming that the tire is used up to 100% wear, a tire with a tire treadwear index of 200 or 300 is changed 3 times and when a tire with a treadwear index of 400 or 500 is preferred instead of this tire, the tire is changed only once. Depending on this tire change, the cost of tires for 10 years (160000 km) of a 4-wheeled vehicle is as in Figure 9.

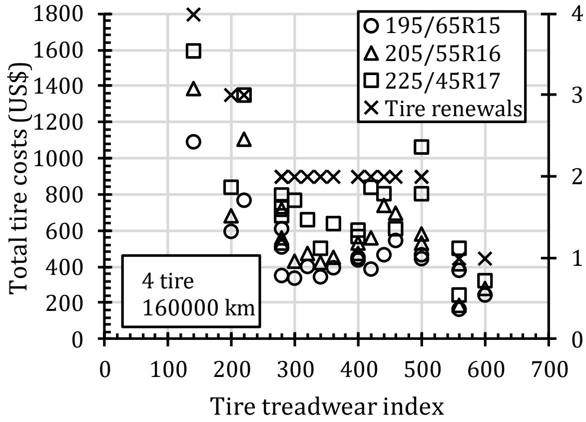

Figure 9. Total tire costs change depending on treadwear index

In Figure 9, it is seen that the increase of the tire treadwear index decreases the total tire cost. When an economic evaluation is made, it is advantageous to use a tire with a high tire treadwear index.

3.2. Environmental Effect

It is expressed by the emission of particulate matter (PM) from the wear of vehicle tires, and these particles are inhalable (PM2.5 and PM10) [19]. However, when all the particulate matter from tire wear is considered to be rubber, the carbon dioxide equivalent can also be expressed as emissions. As the treadwear index increases, it is seen that the particle emission decreases.

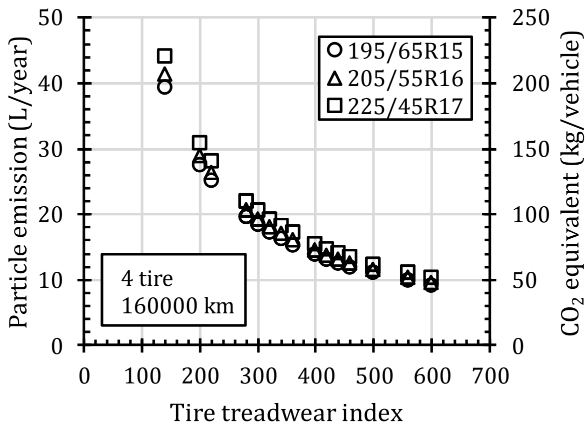

Figure 10. Environmental effect of treadwear index

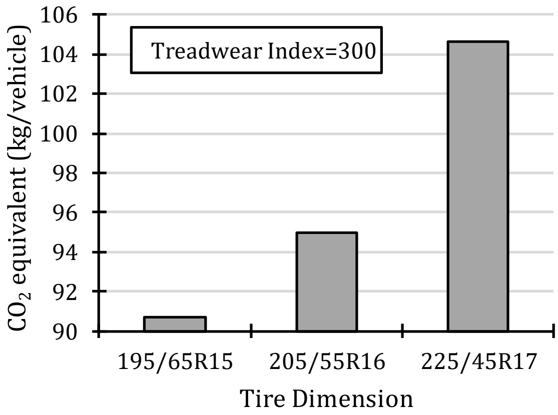

Figure 11. Emission dependent on tire dimension

Although all three tires are equivalent in diameter, they are not equivalent in width, so emission increases as the tire width increases (Figure 10). The emission reduction is reduced by about 15% when less tire width is used. However, emissions are reduced by approximately 76% when tires with high treadwear index are used.

3.3. A Brief Summary of the Results

The environmental and economic effects of tire treadwear are often overlooked. An average passenger vehicle using fossil fuel emits approximately 0.25 kg of CO2e/km (≅404 g CO2e/mile) [21]. This is 40 tons of CO2e when calculated for 160000 km, which is equivalent to 10 years of use in the above calculations. This equates to approximately 400 times the emission caused by tire treadwear of a vehicle. The CO2e value can be reduced using hybrid-electric or electric vehicles, and even reduced to zero shortly when using renewable energy in electricity production. However, the radical reduction of CO2e caused by tire wear does not seem to be possible for now. For this reason, it is seen that tire wear is minimized even if the environmental impact of tire treadwear is not eliminated by making the tire choice consciously. The main concern for vehicle users is not emissions from tire treadwear, but economic reasons. However, the absence of a significant relationship between the treadwear index and the tire sales price causes the treadwear index criterion to be ignored in the tire selection.

4. Conclusions

In this study, the economic and environmental effects of the tire treadwear index were examined using the price and tire treadwear index values for 7 different tire manufacturers, 20 different tire models and 3 different tire sizes for these tire models. Tire manufacturers and models are randomly selected from well-known manufacturers. However, equivalent tire sizes with different rim diameters were chosen. A very useful tire wear scenario has been created for this study. Interesting results were obtained by applying this scenario. There was no significant relationship between the tire treadwear index and tire prices. However, when the prices of tires with the same features are compared, it is seen that they are very variable according to manufacturers. As the tire treadwear index increases, the number of tire renewals that the vehicle has to make during its economic lifetime decreases. This creates an important economic advantage. The tire with a low tire treadwear index has more tire wear, so the amount of particles they emit to the environment is high. For this reason, using a high tire treadwear index tire also provides an environmental advantage. In equivalent tires, the rim diameter and tire width are directly proportional. Therefore, for tires with the same treadwear value, the amount of particle becomes higher as the rim diameter increases. However, in terms of the amount of particulate matter, the treadwear index is a more effective parameter than the rim diameter. However, it should not be ignored that the tire price increases as the rim diameter increases. Considering that the particulate matter formed due to tire wear is rubber, emission of particulate matter can also be expressed as carbon dioxide equivalent (CO2e). It has been determined that during the economic life of a vehicle (about 10 years) it will generate approximately 50-220 kg of CO_2. At least 4 trees should be planted per vehicle to eliminate this emission [20]. Assuming that there are millions of vehicles involved in traffic, this is a great value to be underestimated. The results of the study are especially important and interesting for vehicle manufacturers and tire dealers. However, this study provided very practical information, especially in terms of assessing the economic and environmental effects of vehicle owners' tire choice.

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