

TRAFFIC AS A SOURCE OF RENEWABLE ENERGY: WIND AND NOISE ENERGY

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ABSTRACT

Today, renewable sources are considered one of the key sources of energy. Although traffic is considered one of the problems in large cities, it can be used for energy production. The kinetic energy of the wind generated by the movement of cars is utilized by wind turbines to produce electricity, while the sound produced, as a form of mechanical energy, can be converted into electricity using piezoelectric materials. This research aims to examine the noise levels, as well as the wind strength generated by traffic on the M18 highway in Tuzla, and their conversion into electrical energy to be used for street lighting.

Keywords: wind, traffic noise, electrical energy

1. INTRODUCTION

Great concern about climate change and the need to reduce greenhouse gas emissions has led to the necessity of utilizing alternative energy sources [1]. As a result, efforts are being made to find solutions that minimize sources of pollution and convert them into something functional. A significant form of environmental pollution, which often remains overshadowed by air, water, and soil pollution, is noise, particularly the noise produced by traffic [2,3,4]. This noise can be a "hidden" alternative source of electrical energy that, through the use of piezoelectric materials with high sensitivity to vibrations, can be converted into electricity, in accordance with the law of conservation of energy [5,6]. Most piezoelectric materials are ceramic in nature, although there are also some polymer materials used for specialized applications [7,8,9]. In addition to noise, moving vehicles also produce airflow (wind), the kinetic energy of which can be converted into the rotational kinetic energy of a turbine, and subsequently into electrical energy [10]. The wind pressure varies depending on the size, speed, and mass of the vehicle. This generated wind causes a drag force, which is the force that occurs when a body moves through a fluid medium [11]. The turbulence caused by vehicles moving on roads is called Vehicle-Induced Turbulence (VIT) [12,13,14], and by placing turbines in close proximity to the vehicles, only the wind resulting from the interaction of the vehicle with the air is monitored, minimizing external meteorological influences. The generated electrical energy would be stored in batteries and used to illuminate highways at night.

The first prototype of a skyscraper that would harness urban noise and convert it into usable electrical energy, built alongside a main road, was created in 2013 by Bourgeois et al. from France [15]. In 2009, Browne et al. designed a skyscraper in Chicago that would utilize not

only noise but also wind energy and convert it into usable electricity [16]. T. F. Wiegel and K. C. Stevens patented an electric generating device for capturing wind in 2006, which consists of multiple generators powered by traffic-induced wind [17]. Wind turbines that generate energy from passing traffic are the latest breakthrough in the field of clean energy, appearing on the streets of Istanbul, Turkey, and the idea originated in 2021 from entrepreneur Kerem Deveci [18].

The aim of our research is to examine the usability of noise and wind generated by moving vehicles, i.e., whether the energy produced in these ways can be converted into electrical energy, in what quantities, and whether those quantities are sufficient to be used for street lighting.

2. MEASUREMENT PROCEDURE

For the purpose of investigating the potential utilization of wind kinetic energy and acoustic energy generated by traffic, field measurements were conducted along the M18/M4 highway in Tuzla (yellow circle in Figure 1), where the speed limit is 70 km/h .

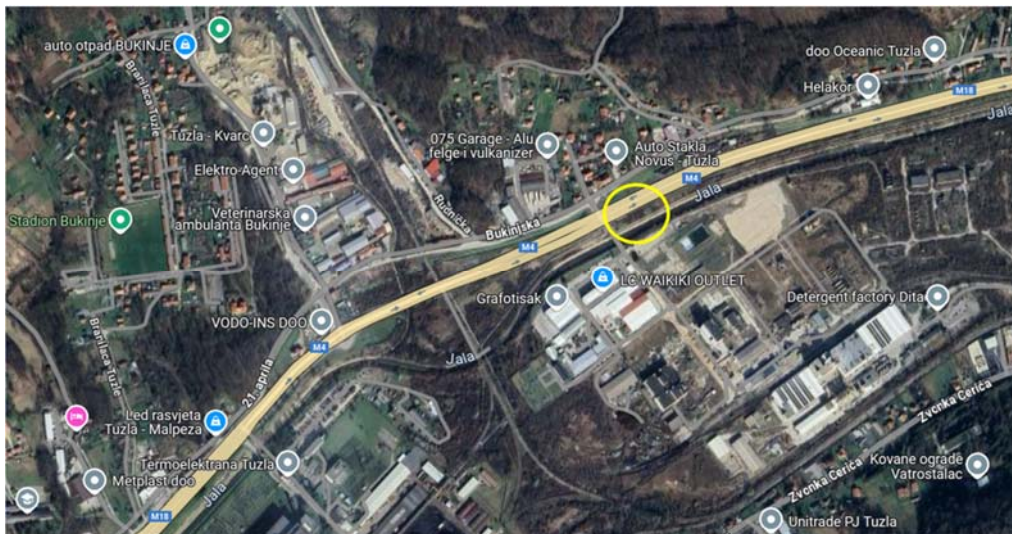


Figure 1. Location of the measurement site adjacent to the M18/M4 highway in Tuzla, Bosnia and Herzegovina.

The primary objective of the measurements was to quantify the average and maximum values of wind speed and noise levels caused by passing motor vehicles in order to assess the energy potential of these sources for possible conversion into electrical energy.

Wind speed was measured using a PCE-AM82 digital anemometer, capable of detecting low airflow rates, making it suitable for microclimatic analysis in urban conditions. The instrument was placed at a height of 1.5 meters above the ground, at a distance of 1 meter from the edge of the roadway, ensuring the measurement of the direct impact of turbulence caused by vehicle passage. The measurements were conducted for a duration of 25 minutes and under minimal natural wind speed conditions. Instantaneous, maximum, and average wind speeds were recorded every minute. Sound level was measured using a PCE-222 sound level meter, which includes an integrated acoustic sensor capable of displaying real-time sound levels in decibels (dB), as well as recording average and maximum values. The instrument was mounted on a tripod at a height of 1.1 meters and positioned 5 meters from the edge of the roadway. Both average and maximum noise levels were recorded, with special attention paid to the frequency of vehicle

passage and the types of traffic units (e.g., passenger vehicles, freight transport, buses), as different vehicle types generate varying noise amplitudes.

During each measurement interval, ambient air temperature was also monitored to allow for additional interpretation of results. Temperature variations can influence air density and the propagation of sound waves, which is relevant for subsequent calculations involving correction factors, energy efficiency, and conversion potential.

3. RESULTS AND DISCUSSION

A very high number of vehicles in traffic causes continuous and rapid air turbulence on roadways. The magnitude of this generated turbulence depends on the speed and timing of vehicle movement. If this turbulence, or the resulting wind, is tactically captured under suitable conditions, the energy can be directed and harvested.

The average wind power, generated by passing vehicles, can be estimated using the following adapted relation from [19]:

$$\bar{P} = \frac{1}{N} \sum_{i=1}^N \frac{1}{2} \rho S v_i^3 \quad \dots (1)$$

where:

\bar{P} - average wind power [W], ρ - air density [kg/m^3], typically taken as $1.184 \text{ kg}/\text{m}^3$ at 25°C , S - effective rotor (turbine) area [m^2], v_i - instantaneous wind speed [m/s], N - number of measurements. The maximum recorded wind speed during the afternoon measurement period was $5.2 \text{ m}/\text{s}$, while the minimum was $0.8 \text{ m}/\text{s}$. These values reflect the variable nature of airflow caused by vehicles moving at different speeds and frequencies.

Assuming the installation of a wind turbine or a series of turbines at strategic roadside locations, and based on calculations using a rotor diameter of 1 meter (resulting in a swept area of approximately 0.785 m^2), a significant amount of electrical energy could potentially be harvested. According to Betz's Law, the maximum extractable power from wind using an ideal turbine is limited to 59.3% of the wind's total kinetic energy, an upper bound known as the Betz limit [20]. In real-world application, the actual efficiency of small turbines is lower, $\eta = (20 - 40) \%$ [21], and in the calculation of usable power $\eta = 30 \%$ is taken. Figure 2(a) shows the dependence of the average and usable power on the wind speed of passing vehicles, while Figure 2(b) shows the calculated power values over time.

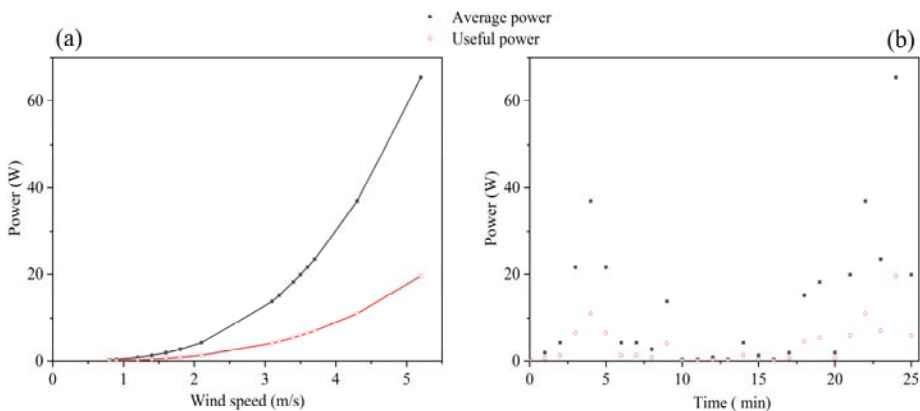


Figure 2. Dependence of power on wind speed generated by passing vehicles (a) and elapsed time (b).

In addition to these data, usable power and accumulated energy per day (calculated for a 12-hour period) were also estimated (Table 1). This energy is insufficient to power a single streetlight; however, a greater number of turbines has the potential to generate a larger (sufficient) amount of energy. It was also observed that larger vehicles, such as trucks and buses, produce higher wind speeds compared to smaller vehicles. This results in higher power values, as seen in Figure 2(b), which was also demonstrated by Al-Aqel et al. [22]. Furthermore, they showed that the optimal position for a wind turbine is 1.0 meter from the roadside, at an appropriate height above the ground, with an optimal orientation of 45° relative to the road, parameters similar to those chosen in our study.

Table 1. Calculated values of average and usable power obtained from traffic-generated noise and wind.

Source	Average Power (W)	Usable Power (W)	Usable Power for 12h (W)	Energy for 12h (kJ)
Wind	7.15	2.14	25,74	92,67
Noise	$2.63 \cdot 10^{-5}$	$0.79 \cdot 10^{-5}$	$9,47 \cdot 10^{-5}$	0.34

As well as wind energy, the noise generated by vehicles in traffic can also be functional. However, high noise levels can cause serious health problems [23,24]. For this reason, laws around the world, including in Bosnia and Herzegovina, aim to regulate the maximum allowable noise levels to protect public health and preserve environmental quality. In the Federation of Bosnia and Herzegovina, the laws regulating noise are the Law on Noise Protection/„Zakon o zaštiti od buke“ („Službene novine FBiH“, br. 110/12) [25] and in the Tuzla Canton, the Law on Noise Protection/„Zakon o zaštiti od buke“ („Službene novine TK“, br. 3/16) [26].

In addition to being a form of environmental pollution, noise is also a type of acoustic energy that can be converted into electrical energy. The passage of a large number of vehicles registers varying noise levels over time. The highest recorded sound level was 85.2 dB, while the lowest recorded level was 69.1 dB. The average sound level, with temperature correction, was calculated from the graph of sound level versus elapsed time (Figure 3) and was found to be 74.20 ± 1.65 dB.

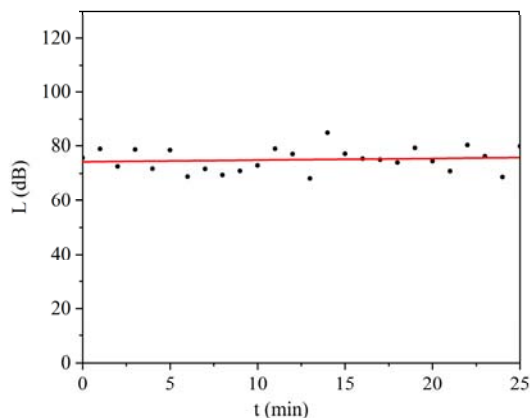


Figure 3. Dependence of sound level on elapsed time.

The correction for temperature $\tau = 25\text{ }^\circ\text{C}$ was calculated using the following equation:

$$\Delta L_{temp}(\tau) = Kx(20 - \tau) \quad \dots (2)$$

where K is a constant, which varies depending on the type of vehicle. It is $0.08\text{ dB}/^\circ\text{C}$ for light vehicles with a mass ≤ 3.5 tons and $0.04\text{ dB}/^\circ\text{C}$ for heavy vehicles with a mass > 3.5 tons, for all types of road surfaces [27].

Knowing the average value of the sound level, the sound intensity \bar{I} can be easily calculated by deriving it from the following equation:

$$\bar{L} = 10 \log \frac{\bar{I}}{I_0} \quad \dots (3)$$

where $I_0 = 10^{-12}\text{ W}/\text{m}^2$ - is the threshold of hearing.

The average acoustic power was calculated using the relation adapted from [28]:

$$\bar{P} = \iint_S \bar{I} dS \quad \dots (4)$$

Assuming that the intensity is constant over the surface S (with a value of 1 m^2) the average acoustic power can be simply calculated using the following relation $\bar{P} = \bar{I}S$.

The values for average and usable power with an efficiency coefficient of 0.3, as well as the usable power and accumulated energy per day, are shown in Table 1. These values are very small, so in order to obtain greater noise usage, a very large number of piezoelectric transducers distributed over a large area is needed, as designed by Browne et al. [16].

4. CONCLUSION

The noise and wind generated by vehicles in traffic can be harnessed to produce useful energy (street lighting). Although a single wind turbine may not provide adequate energy production, a group of turbines placed along a long stretch of highway has the potential to generate a significant amount of energy. With the development of new materials, noise, as a form of pollution, can become a source of useful energy. While the energy generated by noise is very small, with a large number of piezoelectric converters distributed across large areas, there is potential for application in street lighting. There are still questions regarding costs and benefits that scientists need to address, making this technology more efficient and feasible. This design concept is envisioned as sustainable and environmentally friendly.

5. REFERENCES

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