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Simulação da implantação de dispositivo de energia piezoelétrica em pavimento de cruzamentos urbanos

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Abstract

Energy Harvesting is a concept that aims to transform the weight of the vehicle traveling on a track into electrical energy, converting mechanical pressure into electricity, it is the principle of piezoelectric technology currently being tested on highways and urban roads around the world. This type of energy varies depending on the load quantity of the vehicle and the number of times it passes, consequently, this form of energy is discontinuous, being the best use when used on roads with a high flow of vehicles. In this context, a study based on the implementation of piezoelectric devices at an urban intersection with traffic lights in three Brazilian cities with different ports is presented: Marau, Erechim and Passo Fundo. Piezoelectric energy still shows the initial phase of technological and experimental development, but it shows the potential for use in the urban environment, mainly due to the concentration of light vehicles, speeds and as a complementary alternative existing in the existing electrical network.

Keywords: Energy Harvesting; Piezoelectric devices; Urban pavement

Resumo

Energy Harvesting é o conceito que visa transformar o peso do veículo que trafega sobre a pista em energia elétrica, converter pressão mecânica em eletricidade, este é o princípio da tecnologia piezoelétrica em teste atualmente em rodovias e vias urbanas pelo mundo. Este tipo de energia varia em função da grandeza da carga do veículo e do número de vezes que o mesmo passa, consequentemente essa forma de energia é descontínua, sendo melhor aproveitada quando empregada em vias com alto fluxo de veículos. Nesse contexto, apresenta-se um estudo baseado na simulação de implantação de dispositivos piezoelétricos em um cruzamento urbano com semáforo em três cidades brasileiras de portes distintos: Marau, Erechim e Passo Fundo. A energia piezoelétrica ainda se mostra em fase inicial de desenvolvimento tecnológico e experimental, contudo se mostra com potencial de utilização em meio urbano, principalmente pela concentração de veículos leves, velocidades operacionais e como fonte complementar à rede elétrica existente.

Palavras-chave: Energy Harvesting; Dispositivos piezoelétricos; Pavimento urbano

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1 Introduction

There are different ways to generate electricity through road pavements and urban roads, among them: photovoltaic panels, thermal, geothermal and piezoelectric collectors, electromagnetic pickups and wind devices. In these places, renewable energy equipment can be applied specifically to pavements, where there is a large amount of wasted energy, such as mechanical energy generated by vehicles and wind; as well as the thermal energy and incident solar radiation. These energy potentials could supply sensors, scales, cameras and lighting along the highway, without the need for a power distribution network over long distances and even for recharging electric vehicles.

Table 1 shows a cost comparison for each renewable energy source (US$/kWh) and maturity level (NM). NM-1 means that the technology is at a basic research level, while NM-9 indicates implementation of the new technology with an existing system; It is important to note that both the cost and the level of maturity vary according to the progress of studies and government incentives. The new technologies predominantly start their processes with high costs and a low level of maturity, but the current technological advances cause very rapid changes in this scenario, a fact that promotes the importance of studies of new technologies.

Table 1 – Comparison between renewable energy technologies in microgeneration

N.	**Renewable energy**	**Cost US$/kWh**	**N.M (1-9)**
1	Pothovoltaic	0,45	9
2	Solar collectors	4,21	4
3	Thermoelectric	95,74	3
4	Geothermal	0,16	9
5	Piezoelectric	106,38	4

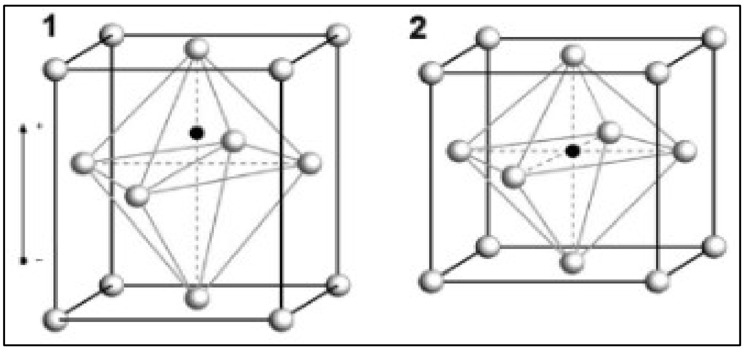
(Adapted: Wang, 2018)

The objective of this study is to investigate the potential of piezoelectric energy that would be generated in urban intersections of cities with populations between 40,000 and 200,000 inhabitants; thus, with geometric characteristics of different roads and active traffic. For this purpose, the simulation of implantation of piezoelectric devices at intersections of urban roads located in the center of the cities of Marau, Erechim and Passo Fundo, located in the State of Rio Grande do Sul, Brazil, is analyzed. Through the energy potential data obtained, it is compared through the consumption of some usual electronic equipment in the urban environment; as well as for the energy demand of the traffic light device located at the intersection evaluated in terms of autonomy.

2 Piezoelectric Energy

The piezoelectric effect - from the Greek: pressure electricity - was discovered by the brothers Pierre and Jacques Currie in 1880. It is the characteristic that certain crystals have of releasing electrons proportionately in response to mechanical pressure. It occurs because piezoelectric crystals have electrically neutral atoms inside that do not have a symmetrical internal arrangement, their electrical charges are perfectly balanced - positive charge cancels negative charge - that is, the electric dipole moments cancel each other out. Therefore, if a mechanical pressure is applied to a piezoelectric crystal, deformation of its structure will occur, causing some atoms to be closer and others more distant (Figure 1); thus, disturbing the balance between positive and negative charges, creating a potential difference (DDP) with negative and positive charges on opposite sides of the crystal faces (there is no cancellation of the dipole moments).

Figure 1 – PZT piezoelectric crystal structure



(1) resting situation (2) after mechanical pressure

(Source: Malmonge, 2008)

In summary, materials having piezoelectric characteristics generate electricity when subjected to mechanical stresses, or conversely, generates distortion by applying an electric field over the same. This behavior has brought the attention of researchers in various sectors and recently, the possibility of applying the paving area for studies of the possible potential of this technology.

In the transport engineering industry, piezoelectric devices can be adapted in the suspensions of the vehicle or else embedded in the pavement structure from the voltage transforming the deformation applied by the vehicle into electric energy.

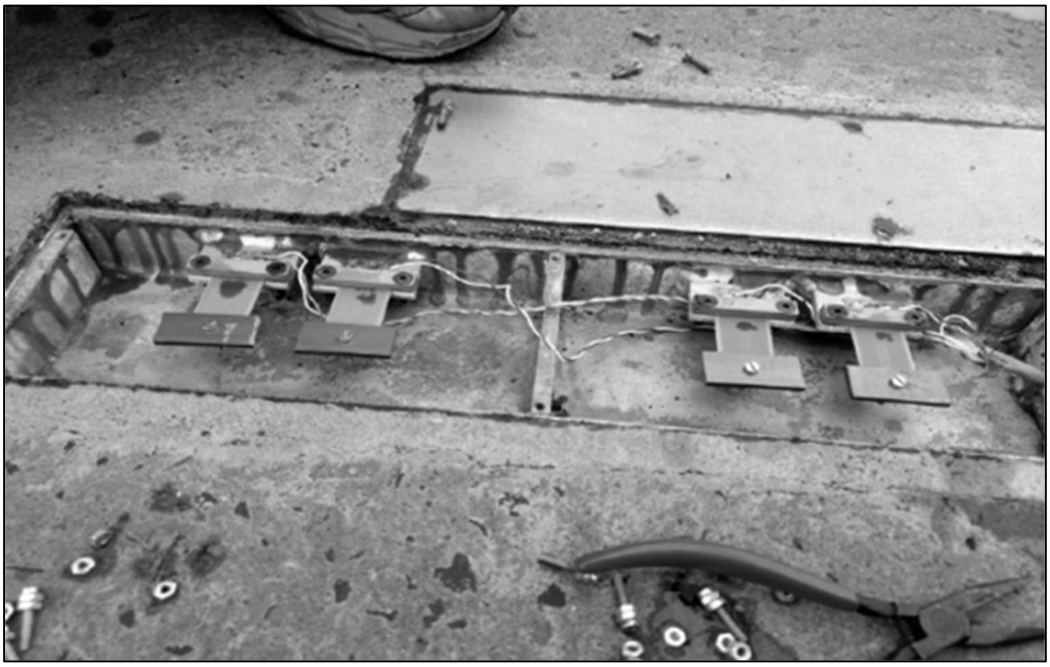
3 Road Use Potential

According to Zhao, Ling & Yu (2012), piezoelectric plates placed along 1 km of highway, would be able to generate enough electricity to supply 2,500 houses (200 kWh per traffic lane). This estimate considers a volume of 600 heavy vehicles per hour of average active traffic.

In terms of road concessions, a toll plaza is a structure with intense energy demand, thus requiring stable and economically attractive energy. One of the important aspects of highways close to metropolitan areas is that the greatest flow occurs at peak energy supply times; this means that toll plazas require more energy to operate at higher tariff hours. In order to have a sustainable concept, it is necessary to embrace several types of devices that can better subsidize the micro-management of demands. In this sense, Tomazini et al. (2018), implemented a pilot system of microgeneration of energy through 16 piezoelectric transducers - 4 boxes with 4 sensors each (Figure 2) - in the toll plaza of BR-290 / RS [km 76 + 000 PS], aiming at the electric supply of a road signaling system composed of tacks with LED lamps forming a strobe effect in the lane intended for the passage of vehicles with automatic tariff payment.

(Continue...)

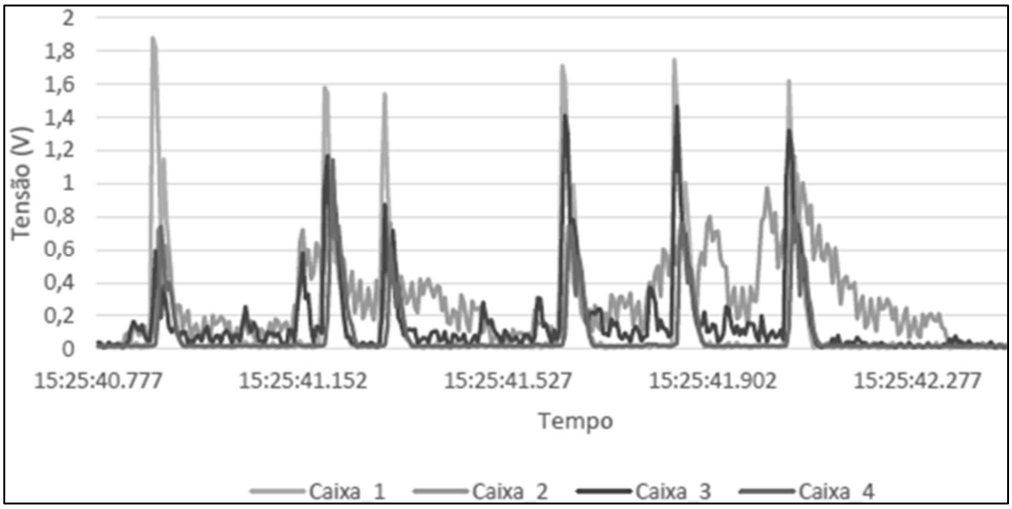
Figure 2 – Piezoelectric transducers installed on the road pavement



(Source: Tomazini et al., 2018)

The piezoelectric devices installed by Tomazini et al. (2018) showed obtaining average voltage peaks around 1.7V when considering the passage of a 6-axle truck: Figure 3 shows the voltage peaks per axis of this study. The registered passage of the vehicle in question allowed the power calculation (Ohm's Law) considering the 3 seconds of duration: average power of 0.981 μW and maximum power of 36.1 μW.

Figure 3 – Voltage spikes generated by the passage of a 6 axle truck



(Adapted: Tomazini et al., 2018)

Through the studies presented, it is of great value to continue research with piezoelectric materials on highways so that the Energy Harvesting devices are improved; considering the mechanical efforts of the surroundings, auxiliary energy capture devices and the constructive characteristics of the pavement layers; as well, so that this technology becomes more attractive financially.

4 Potential for use on urban roads – Methodological aspects

It is known that the energy potential of piezoelectric sensors is dependent on the volume of active traffic and the weight of passing vehicles on the site. However, in terms of the intensity of the load acting on the pavement, the greater it is, the greater the shear stresses imposed on the structure and the greater the fatigue of the coating; that is, there is a decrease in the performance of the pavement (requiring interventions in the order of maintenance and restoration). Therefore, having the potential for piezoelectric devices to suffer early malfunctions or require maintenance in less time due to degradation or due to the pathologies originating from the floor. In this way, use on urban roads is shown to have a certain advantage; since there is restriction of cargo vehicles on certain roads (municipal transport planning) and concentration of flow in urban intersections (greater volume of traffic).

In order to verify the energetic potential of the use of piezoelectric sensors in urban streets, the installation of piezoelectric devices at the following intersections with traffic lights was considered:

Marau/RS: Avenida Julio Borella e a Rua Darvin Marosin;

Erechim/RS: Avenida Mauricio Cardoso e as Ruas Itália e Nelson Ehlers;

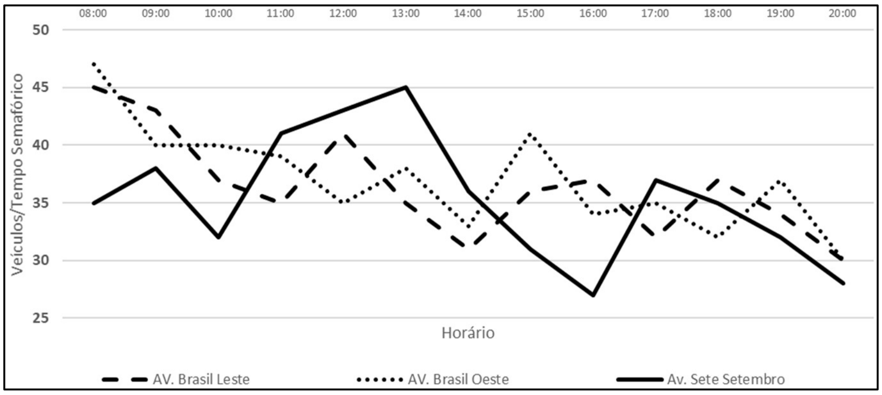
Passo Fundo/RS: Avenida Brasil Centro e a Avenida Sete de Setembro

At these points there is a large flow of vehicles and municipal buses, with one of the largest volumes of traffic operating on the pavement (piezoelectric devices) and having great energy demand in the surroundings (shopping center, goods and services).

The estimate of the traffic acting on the site was made by counting passing vehicles in 5 traffic lights per hour in each direction, considering only the time of coming and going of people, goods and services in commercial terms (8: 00-20: 20: 00h) of a business day, without considering motorcycles and bicycles.

The crossing chosen in Passo Fundo has a 2-time traffic light, 1:30 min. on Av. Brasil (east and west directions) and 0:30 min. on Av. Sete de Setembro (northbound). Therefore, each traffic light time is 2 minutes, as the count was performed in 5 traffic light times per hour, in each one hour interval 10 minutes of the flow passing through the intersection were verified. The average vehicle data by traffic light are shown in figure 4.

Figure 4 – Average vehicle traffic per traffic light between 08:00h-20:00h in Passo Fundo



At the intersection of Marau, the signal time is 90 seconds, considering the count of 5 times per hour, a period of 7.5 minutes per hour was analyzed. In the following figure 5, the average number of passing vehicles is exposed in a traffic light of each hour of the day, considering the analysis in the period from 8:00 to 20:00.

In Erechim, the crossing also has a signal time of 90 seconds. Figure 6 shows the average data of vehicles passing by traffic light.

Figure 5 – Average vehicle traffic per traffic light between 08:00h-20:00h in Marau

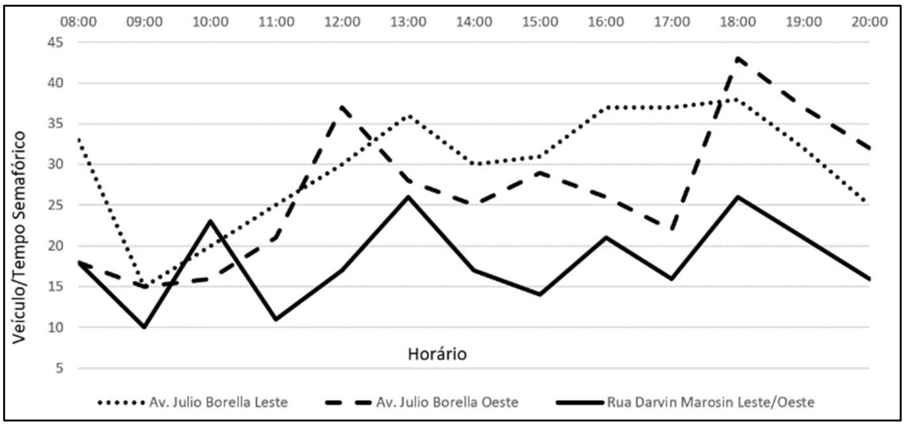
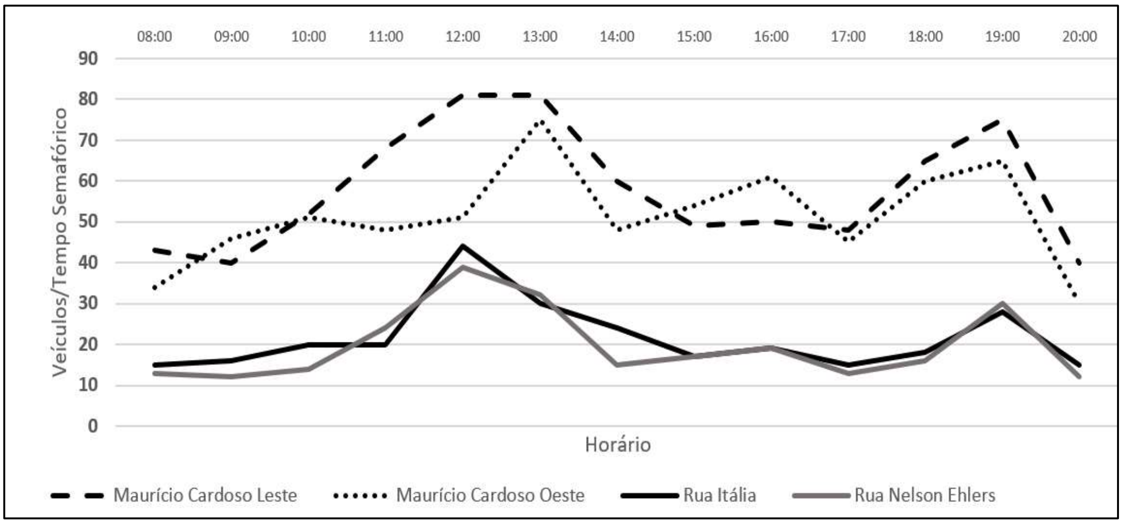


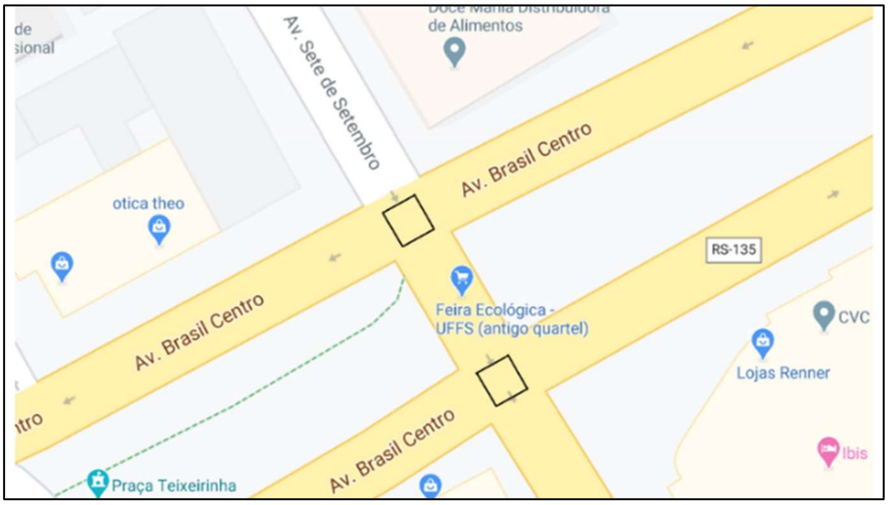
Figure 6 – Average vehicle traffic per traffic light between 08:00h-20:00h in Erechim



The implementation of the piezoelectric pavement was considered in specific areas where the vehicle crossed the road in a straight line (disregarding the conversion maneuvers on the left and right); thus, optimizing the total area of implantation of the devices and the request of traffic loads). For load configuration purposes, a 1,300 kg type vehicle, tire / pavement contact pressure of 2.25 kgf / cm was considered, as obtained by Tomazini et al., 2018.

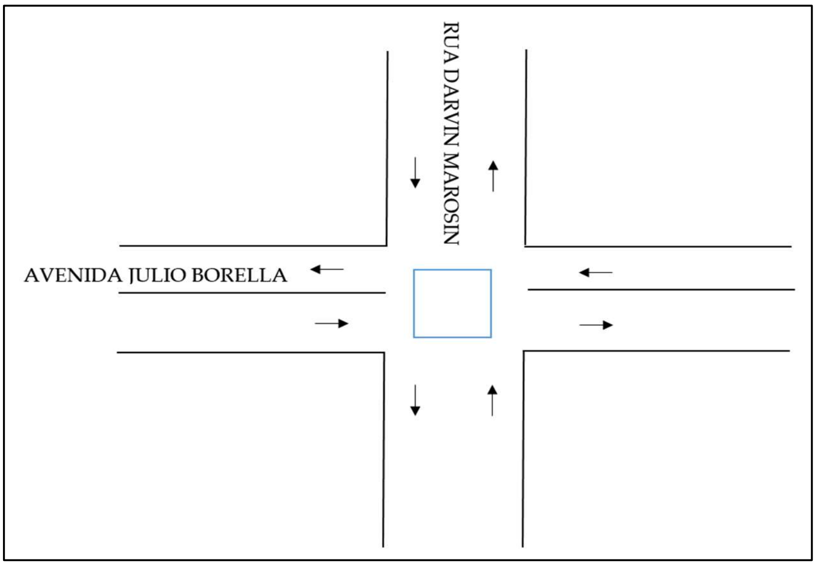
In the case of Passo Fundo, two 10mx12m areas were considered, totaling 240m² of areas containing piezoelectric devices, as shown in figure 7.

Figure 7 – Indication of the crossing areas of Passo Fundo with simulation of implantation of piezoelectric devices



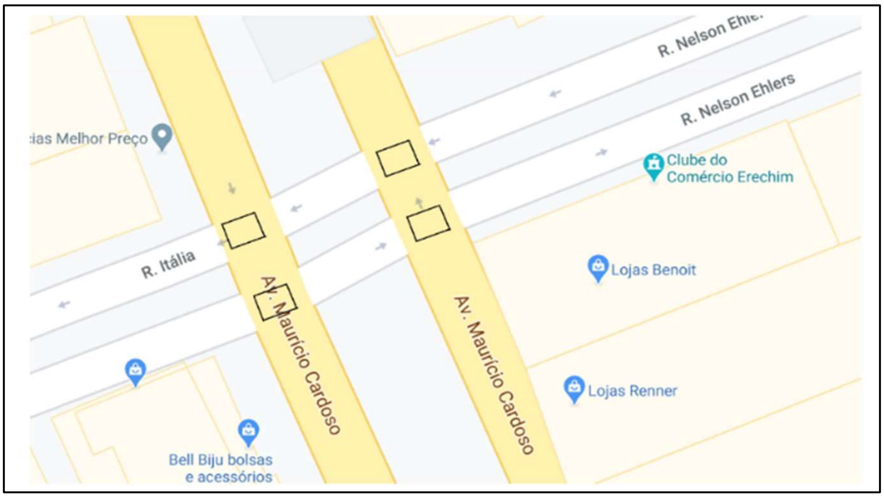
In Marau, on the other hand, due to the geometric configuration of the intersection, it would be necessary to have only one implantation area for the devices, with dimensions of 9mx9m, that is, 81m², as shown in an illustrative way through figure 8.

Figure 8 – Indication of the crossing areas of Marau with simulation of implantation of piezoelectric devices



In Erechim, in order to better take advantage of passing vehicles, it would be interesting to deploy 4 areas with piezoelectric devices, each of these areas being 9mx6m, totaling 216m² of implanted area, the location of each of these can be seen in figure 9.

Figure 9 – Indication of the crossing areas of Marau with simulation of implantation of piezoelectric devices



The estimate of traffic active at the time determined in the survey carried out in the three cities is shown in Table 2.

Table 2 – Traffic estimate for each city at the crossroads of implantation of devices during the period of 08:00h às 20:00h

City	Number of vehicles / day
Passo Fundo	56220
Erechim	31312
Marau	7792

Based on the prototype of a piezoelectric sensor developed by Yesner (2017), presented through figure 10, and adapting the data obtained by the researcher to the charge composition considered in the present study, an energy density of 3.87 Wh / m² for the passage of 500 vehicles.

Figure 10 – Piezoelectric sensor prototype

(Source: Yesner, 2017)

Also, knowing that the mechanical demands of the wheels will not occur in the entire area of installation of the plates, the linear meter action of sensors along the vehicle's path was considered, each piezoelectric device (plate) measuring 0.40x0.40m.

Depending on the implantation area of each crossing, the number of possible plates in each direction was calculated, taking into account the plate dimensions. For each area of the crossing of Passo Fundo, in the direction of Av. Brasil, the placement of 30 plates was simulated and in the direction in Av. Sete de Setembro 25 plates, it is worth mentioning that the vehicles that travel through Av. Sete de Setembro request the two areas, generating greater energy range.

In Marau, as there is only one area of piezoelectric sensors, 23 plates could be added in each direction of the crossing.

In the case of Erechim, each area will have 23 signs towards Av. Maurício Cardoso and 15 streets in the direction of Rua Itália and Nelson Ehlers. As the execution of 4 areas was admitted, each passing vehicle on both roads had requested two license plate areas.

5 Results

Table 3 shows the quantitative potential of electrical energy generated by the installation of 240 m^2 of piezoelectric sensors at the urban intersection between Av. Brasil and Av. Sete de Setembro, in the city of Passo Fundo / RS.

Table 3 – Potential for generating electricity using a piezoelectric pavement on na urban road (traffic light crossing in the city of Passo Fundo)

Schedule	Av. Brasil		Av. Sete de Setembro	
	Leste	Oeste		TOTAL
08:00	200,62	209,54	130,03	670,22
09:00	191,70	178,33	141,18	652,39
10:00	164,95	178,33	118,89	581,06
11:00	156,04	173,87	152,32	634,56
12:00	182,79	156,04	159,75	658,33
13:00	156,04	169,41	167,18	659,82
14:00	138,21	147,12	133,75	552,82
15:00	160,50	182,79	115,17	573,63
16:00	164,95	151,58	100,31	517,16
17:00	142,66	156,04	137,46	573,63
18:00	164,95	142,66	130,03	567,68
19:00	151,58	164,95	118,89	554,31
20:00	133,75	133,75	104,03	475,55
			TOTAL (W/day)	7671,14

Table 4 shows the potential for electricity generated by the 81m² of piezoelectric plates, if installed in the municipality of Marau.

Table 4 – Potential for generating electricity using a piezoelectric pavement on na urban road (traffic light crossing in the city of Marau)

Schedule	Av. Brasil		Av. Sete de Setembro	TOTAL
	Leste	Oeste		
08:00	30,08	16,41	16,41	62,89
09:00	13,67	13,67	9,11	36,46
10:00	18,23	14,58	20,96	53,78
11:00	22,79	19,14	10,03	51,95
12:00	27,34	33,72	15,49	76,56
13:00	32,81	25,52	23,70	82,03
14:00	27,34	22,79	15,49	65,63
15:00	28,26	26,43	12,76	67,45
16:00	33,72	23,70	19,14	76,56
17:00	33,72	20,05	14,58	68,36
18:00	34,64	39,19	23,70	97,53
19:00	29,17	33,72	19,14	82,03
20:00	22,79	29,17	14,58	66,54
			TOTAL (W/day)	887,76

In addition, through Table 5, the energy potential generated by the plates implanted in the areas of the crossing of Erechim (216 m²) is shown.

(Continue...)

Table 5 – Potential for generating electricity using a piezoelectric pavement on na urban road (traffic light crossing in the city of Erechim)

Schedule	Maurício Cardoso		Rua Itália	Rua Nelson Ehlers	TOTAL
	Leste	Oeste			
08:00	78,39	61,98	17,83	15,46	173,65
09:00	72,92	83,85	19,02	14,27	190,06
10:00	94,79	92,97	23,78	16,64	228,18
11:00	123,96	87,50	23,78	28,53	263,77
12:00	147,66	92,97	52,31	46,37	339,30
13:00	147,66	136,72	35,67	38,04	358,09
14:00	109,38	87,50	28,53	17,83	243,24
15:00	89,32	98,44	20,21	20,21	228,18
16:00	91,15	111,20	22,59	22,59	247,52
17:00	87,50	82,03	17,83	15,46	202,82
18:00	118,49	109,38	21,40	19,02	268,29
19:00	136,72	118,49	33,29	35,67	324,16
20:00	72,92	54,69	17,83	14,27	159,70
				TOTAL (W/day)	3226,97

Table 6 shows a potential comparison of the use of energy obtained by the piezoelectric floor in terms of consumption of devices connected to the electrical network in the period of analysis considered; that is, between 08:00 and 20:00.

Table 6 – Quantitative of electrical appliances that can be supplied by the energy generated by the piezoelectric pavement in each city

Electrical appliance	Consumption (W/h)	Passo Fundo Quantity (08:00 - 20:00)	Erechim Quantity (08:00 - 20:00)	Marau Quantity (08:00 - 20:00)
Full smartphone recharge	4	1279	538	148
Fluorescent lamp	15	43	18	5
Notebook 15''	100	6	3	1
Television 29''	110	6	2	1
Fridge freezer	130	5	2	1
Hair dryer	600	1	0,4	0,1
Air conditioning 7.500 BTU	1000	0,6	0,3	0,1

The potential of using piezoelectric flooring as an auxiliary source of electrical energy is perceived, and it can also be used occasionally in some cases. One of these could be the energy supply of the local traffic light system at the intersection of the piezoelectric pavement.

In this way, using data from Haddad & Yamachita (2015), regarding the energy consumption of LED lights used in urban vertical signaling for vehicles and pedestrians, as well as, considering the traffic light configuration at the crossing in Passo Fundo / RS - 8 vehicular devices and 8 pedestrian devices - total consumption of 337.68 W / h is estimated (16 high brightness LED circuits with Fresnel lens in Red and Green colors and 8 lamps of the same type in yellow). Therefore, the energy generated by the piezoelectric pavement in 12 hours would be able to generate 23 hours of autonomy for the signaling of the site.

In the case of Marau, the intersection studied has 10 traffic light devices for pedestrians and 5 for vehicles, thus, the energy generated at this junction would promote autonomy for 3 hours of signaling the location. In Erechim, the traffic lights at the intersection have 8 devices for vehicles and 8 for pedestrians, causing the necessary energy to keep the equipment running for 10 hours.

Obtaining piezoelectricity on urban pavement shows the following advantages in relation to use on highways:

1) efforts resulting from the loads of the traffic acting with less intensity (lower level of tension in the electronic devices and less need for maintenance of the pavement);

2) greater volume of vehicles, especially when installed at intersections of urban roads;

3) traffic speed control on site, less risk of aquaplaning by possible devices located on the surface of the pavement (possibility when installed in a place where there is speed control by traffic lights);

4) high energy demand in the surroundings (street lighting, road signs, homes, commerce and industry);

5) shorter cabling length to the main electrical network (when used as a complementary energy source);

6 Conclusions

The indices, worldwide, show an increasing demand for energy in recent years. Having space for renewable energies to develop and gain acceptance for full-scale deployment; not in order to replace conventional ones, but in order to add energy potential to the existing network.

The energy obtained by means, as is the case with the piezoelectric pavement, is still in the initial stage of technological and experimental development; however, it shows potential for use in crossroads in urban areas for small and medium-sized cities (40,000 to 200,000 inhabitants).

The piezoelectric pavement on an urban road, on the other hand, is already showing a tendency to be technically and economically viable in the short to medium span of time due to the energy data obtained in the implantation area considered in the present study.

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