HIGH SCHOOL EDITION
Journal of Student Research

Volume 11 Issue 4 (2022)

Modeling Piezoelectricity's Impact on Environmental Parameters with Real-life Applications

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ABSTRACT

With a rapid increase in the global human population in recent years, the Earth is in dire need of alternative energy sources. The objective of this paper is to assess the feasibility of implementing piezoelectricity as a primary source of renewable energy. Specifically, this paper looks at its consequent impact if introduced in 3 fundamental areas of implementation: bus tires, train tracks and railway stations. Each of these areas provide input elements at scale to generate electricity and are simple to implement, maintain and measure through government support. This paper limits the data to the city of Cairo, Egypt. Being low cost as well, the three areas come close to an ideal situation from an economic standpoint. Predictive algorithms and existing data are used to evaluate the consequent change in global green-house emissions and other environmental parameters, had piezoelectricity been previously implemented. The results of the equations show that there would be improved environmental conditions - thus, a net positive impact - that switching to piezoelectricity would have had on the atmosphere and environment. The predictions stay true, provided that the efficiency of the piezoelectric crystal remains constant- an outcome which serves to boost output and lower greenhouse emissions.

Introduction

Non-renewable energy resources constitute Earth's predominant source of energy, with 80% of the world's energy supply stemming from fossil fuels (*Jesse et al., 2011*). With a growing global population, humankind's utilization of these sources has increased by a factor of 20 over the last 200 years (*John P et al., 1991*). Heavy dependence on these exhaustible resources gives rise to a variety of problems: increased carbon-emissions, subsequent global warming, pollution, oil spills, ecotoxicity, and increased carcinogens. Non-renewable resources also release hazardous gasses; they contribute to changing weather patterns, affect food production, alter animal ecosystems, interfere with complex food webs, and reform essential biodiversity present within habitats (*eg. Dincer, Ibrahim; 2000*). Despite having various other harmful effects on the environment and our health, there is no concrete viable alternative that can be immediately implemented.

This paper intends to offer a solution to this problem and remedy the global energy crisis by introducing an alternative renewable energy source: mechanical energy exerted due to pressure. Research on how to create a sustainable and organic solution to the issue, and how daily activities can be utilized as fundamental energy sources was done; the piezoelectric device seemed to cover these requirements. Our piezoelectric device harnesses mechanical energy by utilizing the piezoelectric effect. When pressure is applied through the piezoelectric transducers, the mechanical energy is converted to electrical energy. The electricity can then be routed to a central grid where the energy is stored in a generator and then distributed via channels. Essentially, the device can be applied universally in any physical instance involving a change in pressure or a resulting vibration, making its function quite versatile.

In this paper, the energy crisis is approached by exploring the effect on forecasted temperature and carbon dioxide levels through the modeling of various equations pertaining to the three scenarios (bus tires, train tracks and stations), whilst taking into account various factors. Mathematical models and past climate patterns were developed to predict future states, allowing researchers and readers alike to draw accurate conclusions. It also highlights the degree of change that our piezoelectric device can have on the environment, which is useful as a means of measurement, allowing us to reach a meaningful conclusion.

This paper uses the decrease in the carbon emissions and resulting change in temperature as performance indicators for the model. These are compared to models of existing data of the same in order to visualize results.

We initially began with the shoe as our primary object for testing but quickly realized its limitations. The shoe, although highly applicable, is challenging to put into production and will require a massive change in consumer buying patterns in order to have significant impact. Furthermore, there are issues of creating a systematic way of energy collection that is effortless and simple for the end user. Any central grid systems would also require multiple subsystems to be established in order to route and collect the energy from the shoes which proves to be a costly endeavor. By searching for simple methods of creating a methodical system of collection and dissemination of energy, we realized that government areas of influence would be a suitable sector of application. It then came down to areas where there are high changes of pressure and/or areas with a high frequency of pressure changes. Through this thought process we were able to narrow it down to automotive systems as they contain a large amount of movement and also utilize huge quantities of weight. The most ideal scenarios would be placing the piezoelectric device on train tracks, stations and airplane runways and the resulting energy could be collected and routed directly to a central hub. As they are consistently similar areas of land and the piezoelectric device could be lined on the floor, there is no complex external circuitry required and any cables could simply be placed below the surface and then routed to a hub out of sight. However, for the sake of diversification, we decided to also include bus tires. Despite bus tires being in a relatively harder location to accumulate the energy from, the reason we have selected them is that it displays the diversity and presents a long-term probable location of application.

Mechanism of the Piezoelectric Model

Piezoelectricity was first discovered in 1880 by the French brothers and scientists Jacques and Pierre Curie. The Piezoelectric effect is essentially the creation of electric potential across the sides of a crystal when subjected to mechanical stress (*Bera et al., 2016*). A crystal is defined as a solid whose atoms or molecules are arranged in a regulated, patterned manner and are repetitions of a basic atomic 'building block'. When generating Piezoelectricity, a crystal - usually quartz- is placed between two metal sheets. At this point the charges inside the piezoelectric system cancel out and the material is neutral - there is no net dipole moment. It is important to understand that the molecular structure need not be symmetrical, but the charges have to be present in balance. As mechanical pressure is applied, the pressure deforms and creates a displacement of atoms *(Richard.M.Martin , 1972)* in the quartz, which causes an imbalance in the concentration of positive and negative ions inside the material. This creates a potential difference (and therefore electricity), and the charges are captured by the metal plates which produce's voltage and creates an electric current. This current is an alternating current; hence, in order to be converted into a form that can be usable by end users, it must be converted to a direct current. This is achieved through the use of a full wave rectifier and utilizes 4 diodes in conjunction (*Sahu et al., 2010*)

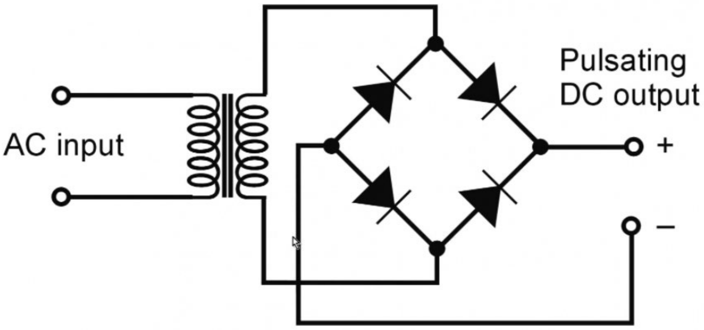

Figure 1. AC to DC conversion circuit diagram

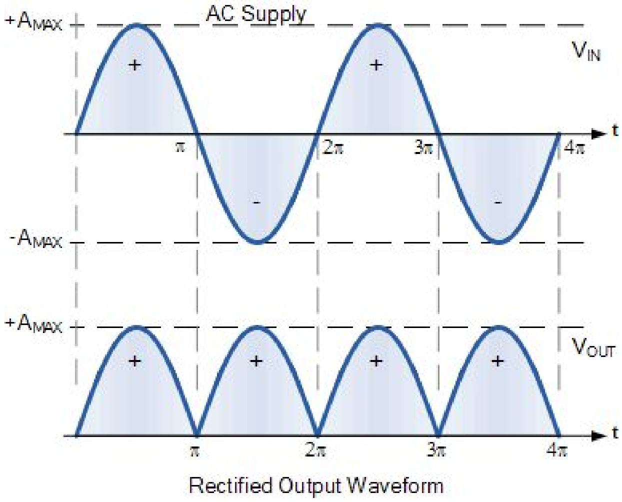

Figure 2- Full Wave Rectification

Had this not been done and the electricity been directly utilized, the constant flux between the positive and negative states of the electricity would have shorted the system's internal circuitry and rendered it ineffective. Once the electricity has been converted, it can then be stored temporarily in capacitors and then routed to a central hub, or sent directly to the central hub based on the area of application.

Methodology and Equations

Each equation of energy as a function of time is modeled by either a linear or exponential model. Each source uses 2012 as the 'base year' for the equation, wherein growth factors (linear or exponential) determine the increase in energy harvested with each year. These equations resolve to an energy/time ($kWh \times y^{-1}$) value, which is applied to the forecasting function in order to calculate further environmental parameters. Additionally, to allow the formulae to appear more comprehensible, the variables in each equation use their word form. For the model of train stations and bus tires, the growth factor components of the model are utilized in order to visualize the type of growth – linear or exponential. However, the values of energy for each year between 2012-2020 (with intervals of 2) were calculated manually using each model's respective data for the base year, and for the following years respectively. In order to derive the energy component of the result, a formula relating power (per piezoelectric device), energy and time (per contraction):

$$Energy = Power \times Time$$

Piezoelectric Source 1: Train Stations

The final equation modeled to calculate the energy accumulated by train stations in 1 year is given by the function $E_1(t)$:

$$E_1(t) = \frac{energy}{step} \times \frac{step}{person} \times \frac{person}{\frac{spot}{day}} \times spots \times \frac{days}{year} \times (k_1)^{t-1}$$

It was assumed that were was an exponential relation between the energy harvested from this source and time based on an exponential model of the population increase of Cairo, with an increase of 2.2% annually ($k_1 = 1.022$). The formula was reached after applying algebraic cancellation. The use of the component of the model containing k_1 is to represent that there is an exponential increase in the number of people walking past a given spot. The average of the number of steps was taken in order to maximize accuracy; for the objective of the research paper, it was assumed to be constant. This could be an area of further exploration as the average number of steps are a changing value, and can be modeled by another equation. This paper observes the effect of implementing piezoelectricity in the Elshohadaa station. Naturally, this value can be scaled to all stations by multiplying the result by the number of stations whilst factoring in the number of steps at each station. Data from research (Elhawagy et al,. 2017) shows that the total number of steps walked by people in a day is 150,000, 1 tile(Waynergy) produces 1500 kWh per day, they share a positive correlation (1000 tiles would produce 1500 kWh×1000) and there is a 2.2% increase in population of Cairo (annual), assume that this translates directly to a 2.2% increase in foot traffic.

Piezoelectric Source 2: Train Tracks

The equation used to calculate the energy harvested from the device's implementation on train tracks is given by the function $E_2(t)$:

$$E_2(t) = \frac{energy}{contraction} \times \frac{contraction}{wheel \times year} \times \frac{wheel}{train} \times train$$

In both scenarios, the energy is calculated by the energy generated per object per spot - only in one case the object are steps and the 'spot' is an area of floor, and in the other the object is a train and the 'spot' is an area of train track. Since increases in all of the variables associated with this model were negligible (compared to those of the other 2 models), a growth component was neglected. Here again, the formula was reached after applying logical and critical thinking and then verified mathematically using the rule of cross cancellation. In this scenario, the uncontrollable variables have been considered constant. (Eg: the number of tracks and the number of trains). Once again, this is an area of further exploration in order to maximize precision, as both of these variables could be modeled by their own functions of time. SEF tiles will be implemented on the rail heads of all operational railway tracks in Cairo. Data from research (Eg: Jeong et al., 2019, AGICO) shows that the width of a rail head is 0.05588m, the total distance covered per year by trains in Cairo is 1287.48 million km, the average speed is 80 kmph, the maximum power generated per device is 50W, and the total operational length of train tracks in Cairo is 5625 km.

Piezoelectric Source 3: Bus Tires

The final equation modeled to calculate the energy accumulated by bus tires in 1 year is given by the function $E_3(t)$:

$$E_3(t) = \frac{energy}{contraction} \times \frac{contraction}{tire \times revolution} \times \frac{tire}{bus} \times bus \times \frac{revolution}{year} + k_2(t-1)$$

Here again the formula was reached after applying logical and critical thinking and then verified mathematically using the rule of cross cancellation in multiplication. The value k_2 refers to the linear growth factor of this model. This component of the model is represented just to show that the model is linear. A source showed that the trend in the number of buses in Cairo from 2015 onwards increased by approximately 12,900 annually. The energy contraction refers to the amount of energy generated when 1 piezoelectric device is contracted. This value varies with the type of crystal, but for the sake of simplicity, a common piezoelectric tile was used for each source. Multiplying this by the number of contractions per tire in 1 revolution results in the amount of energy generated by the tire when 1 revolution is completed. Multiplying this by the number of revolutions completed in 1 year by all buses in Cairo results in the final answer. The number of revolutions per year can be calculated through the formula:

$$\frac{revolution}{year} = \frac{d}{2\pi \mathrm{r}}$$

The value ‘d’ is the total distance traveled by buses in the base year (2012), which is a value that is more readily available in datasets than the total number of revolutions per year. The term $'2\pi \mathrm{r}'$ refers to the circumference of the bus tire. As there are many types of tires, an average of the most common radius was taken; this can be another area with scope of further exploration. Using said radius and the dimensions of the piezoelectric tile, the number of devices per tire was optimized to fit a maximum number. Additionally, for the sake of simplicity, this model assumed that the number of tires per bus wherein the piezoelectric devices were implemented was 4. Since buses and other larger vehicles often contain more than 4 tires, the energy harvested could substantially increase if the number of tires per bus was extended to 8, 12 or even 16. The effect of implementing SEF piezoelectric devices in bus tires in the greater Cairo Area can be determined by the following data: The dimensions of an SEF tile is 40mm×60mm (allowing the number of devices per tire to be 273), the width of a tire is 0.29m, the radius of an average bus tire is 0.381m, the amount of energy generated by SEF devices is 2.27456×10^{-5} J per device, there are 133,673.44 revolutions of tires per day (4 tires per bus), buses travel 320Km in 1 day, the amount of time taken during a device contraction is 5.525×10^{-3} seconds, and the maximum power per crystal is 50W. The energy harvested from the years between 2012 to 2020 was manually calculated using the linear model of the number of buses increasing annually along with the given data.

The values of the 3 scenarios can be added to give a total energy function $E_p(t)$:

$$E_p(t) = E_1(t) + E_2(t) + E_3(t)$$

$$\begin{aligned} E_p(t) = {} & [\frac{energy}{step} \times \frac{step}{person} \times \frac{person}{\frac{spot}{day}} \times spots \times \frac{days}{year} \times (k_1)^{t-1}] \\ & + [\frac{energy}{contraction} \times \frac{contraction}{wheel \times year} \times \frac{wheel}{train} \times train] \\ & + [\frac{energy}{contraction} \times \frac{contraction}{tire \times revolution} \times \frac{tire}{bus} \times bus \times \frac{revolution}{year} + k_2(t-1)] \end{aligned}$$

Extension of Model to Environmental Parameters

This model utilizes the idea that all the energy harvested from the 3 piezoelectric sources can be substituted for energy consumed from natural gas. $C_f(t)$ refers to the CO2 emissions if piezoelectricity will be utilized, $C_i(t)$ refers to the projected CO2 emissions without the usage of piezoelectricity, $E_m(t)$ refers to the projected amount of energy consumed from natural gas.

$$C_f(t) = C_i(t)\,\frac{E_n(t) - E_p(t)}{E_n(t)}$$

This equation calculates the decrease in Energy produced by methane by subtracting the energy produced by Piezoelectricity (as there is a change in the 3 scenarios as to the utilization of the sources of energy~a shift towards piezoelectricity = a shift away from natural gas consumption) from the original amount of energy obtained from methane, and then dividing it by the original amount of energy obtained from methane.
This gives us the decrease in energy produced by methane.

Using a direct relationship and Granger causality present between Carbon Dioxide Mass and temperature (e.g. Kodra et al., 2011, Davis et al., 2017)

$$\frac{T_f(t)}{T_i(t)} = \frac{C_f(t)}{C_i(t)}$$

Substituting this for $C_f(t)$ in the previous equation:

$$\frac{T_f(t)}{T_i(t)} = C_i(t)\,\frac{\frac{E_n(t) - E_p(t)}{E_n(t)}}{C_i(t)}$$

$$T_f(t) = T_i(t)\,\frac{E_n(t) - E_p(t)}{E_n(t)}$$

Results

(Pre-Implementation refers to the true environmental conditions of 2012-2020. Post-Implementation refers to the years 2012-2020 under the condition that energy would have been harvested using the paper's proposed piezoelectric sources, thereby having consequential effects on energy consumed from Natural Gas, CO_2e, and the highest temperature in June. These may be respectively referred to as Pre-I and Post-I.)

Table 1. Energy obtained from piezoelectric sources.

	Energy obtained from Piezoelectric Sources			
Years	**Stations(10^8 ±5×10^4kWh)**	**Buses(10^8 ±5×10^4kWh)**	**Train-Tracks(10^7 ±5×10^3kwh)**	**Total(10^9 ±5×10^5kWh)**
2012	4.959	4.559	6.436	1.016
2014	5.159	5.192	6.436	1.099
2016	5.368	5.838	6.436	1.185
2018	5.585	6.897	6.436	1.313
2020	5.810	7.952	6.436	1.441

Table 2. Pre-Implementation vs Post Implementation Data for CO2e, Energy from Natural Gas, Hottest Temperature in June

	Pre-Implementation			**Post-Implementation**		
Year	**$CO_2e(10^3 \pm 5\times10^3$tonnes/kt)**	**Energy from NatGas($10^{11} +5\times10^7$kWh)**	**Temperature (±0.5 °C)**	**$CO_2e(10^3 \pm 5\times10^3$tonnes/kt)**	**Energy from NatGas($10^{11} \pm 5\times10^7$kWh)**	**Tempera-ture (±0.5 °C)**
2012	212410	5.770	39.000	212040	5.759	38.932
2014	216650	5.210	43.000	216190	5.199	42.909
2016	233960	5.480	44.000	233450	5.468	43.904
2018	240260	6.390	42.000	239770	6.377	41.914
2020	269500	6.330	42.000	268890	6.316	41.904

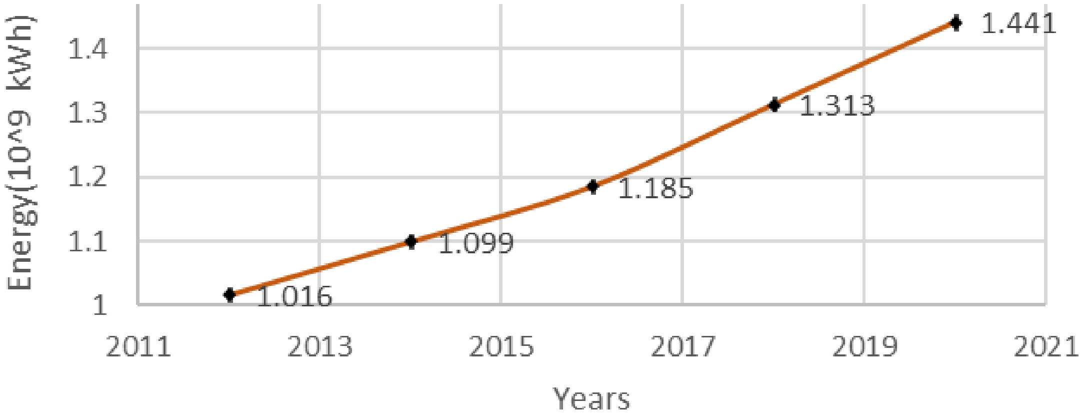

Figure 3 - Energy obtained from the stations, bus tires, and train tracks) from 2012-2020

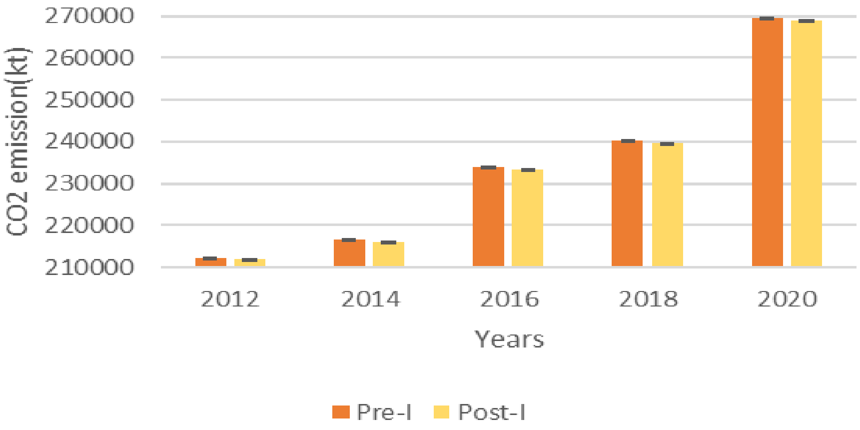

Figure 4 -Carbon dioxide emissions levels Pre-I vs Post-I from 2012-2020

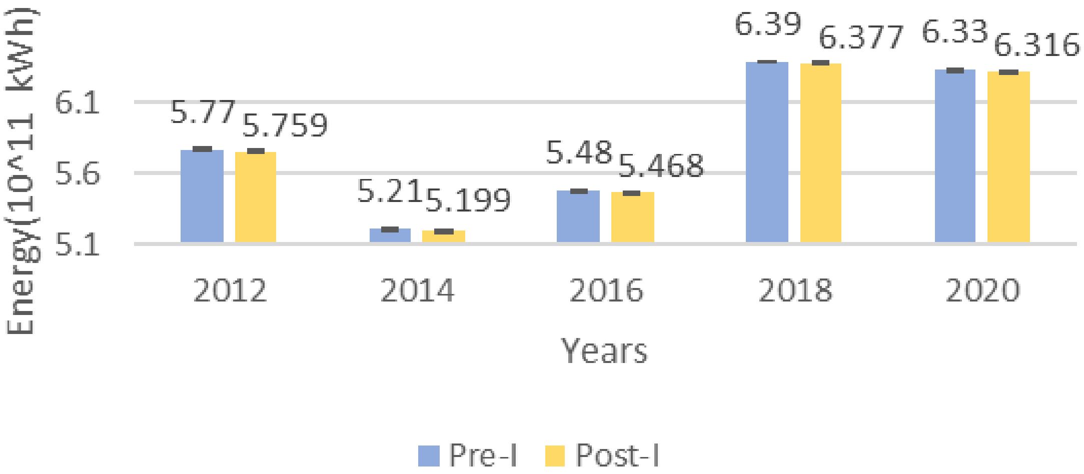

Figure 5 - Energy obtained from Natural gas Pre-I vs Post-I 2012-2020

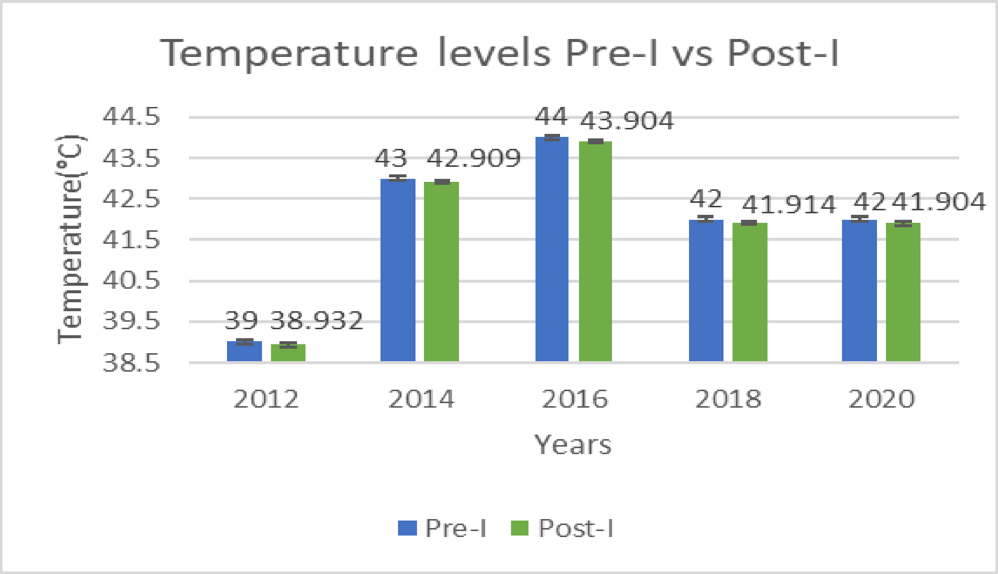

Figure 6 -Highest temperature in June in Egypt Pre-I vs Post-I from 2012-2020

Evaluation

It can be discerned from Figure 1 that a positive correlation exists between the energy obtained from the piezoelectric sources and time. The energy obtained from the piezoelectric sources increases from 1.016×10^9 kWh in 2012 by almost 42% to 1.441×10^9 kWh in 2020. With time, these sources will gradually generate an increasing amount of energy (apart from the 3rd scenario, in which a change factor was negated due to simplicity considerations). In scenario 1(stations), with an exponential increase in Cairo's population annually, foot traffic at train stations is an inevitable increase. In this quantitative model, it was assumed that the population had an annual growth of +2% compared to the previous year. It was also assumed that this +2% would perfectly correspond with a +2% change in foot traffic.

Whereas for scenario 2, this quantitative model was developed under the assumption that the total number of operational buses was increasing linearly, which was modeled using a linear regression of the number of buses against time.

In the following 3 graphs, it can be inferred that the Pre-I and Post-I environmental conditions follow very similar observable trends. Looking back to the derivation of Post-I values, the environmental conditions relied on a simple assumption that served as the foundation for further calculations: Granger causality between carbon dioxide emission levels and temperature levels. By establishing this causality, it was made simpler to use ratios, instead of having to model Carbon dioxide emissions as a function of temperature (or vice versa). The CO2 emissions levels in 2012 have a difference of 370 kt in 2012. This difference, however, rises to 610 kt in 2020. Similarly, the difference in the amount of energy consumed from natural gas in 2012 is 0.011×10^{11} kWh, but increases to 0.014×10^{11} kWh in 2020. The temperature levels in Post-I are almost 0.1 degrees Celsius lower than that of its Pre-I counterpart.

The observable differences between Pre-I and Post-I appear minute due to the fact that the range for the y-axes was relatively large. Furthermore, the units of the y-axis variables for Figure 2 are 10^3 tonnes. This was done in order to standardize the units to kt. However, the true values were in the range of 1.000 to 9.999*10^5. With such large values being plotted, differences in values can much more accurately be noticed using Figure 1(Table). The reason that the graph shows lower carbon dioxide emission values for Post-I than for Pre-I is because an assumption was made that all the energy being harvested from the combined piezoelectric sources would be substituted for energy being harvested from Natural Gas. This allowed us to find the Post-I ideal value of energy consumed from Natural Gas, which would logically be lower than that of Pre-I. With further calculations and the aforementioned established Granger-causalities, our equations were able to show- using the idea that energy from Natural Gas positively correlated with carbon dioxide emissions- that carbon dioxide emissions would be lower for Post-I. Similarly, using the Granger causality, the equations were used to solve for the Post-I temperature values, which - just like energy consumed from Natural Gas and carbon dioxide emission levels- would be lower than its Pre-I counterpart.

It is imperative to note that the predictive algorithm does not account for changes in some of its factors. The predictive algorithm can further be refined by accounting for a multitude of other factors, which were considered to be constant in this exploration for the sake of simplicity. The list for the previously mentioned involves (but is not limited to) consumer trends in bus usage, factors affecting the production of buses and factors affecting the daily activity of people in train stations.

Implications of Results to Society

The energy crisis is the depletion of non-renewable resources without any reduction in demand and consumption. Through simple economics, if there is more demand than supply (i.e. a shortage), the prices will rapidly increase which can have devastating impacts on the global economy. Similar to the 1973 oil crisis in the US, the energy crisis can lead to inflation, recession, unemployment (Williams et al., 2003) and have hazardous environmental effects such as global warming.

Had piezoelectricity been implemented in 2016, energy from the 3 sources would be able to account for approximately 2.63% (Dividing the proposed energy harvested from piezoelectricity by the energy consumed in Cairo in 2016). Although 2.63% seems like a small amount, it is important to note that the energy being harvested from piezoelectric sources would increase at a rate more than that of energy consumed from natural gas. Ideally, this would eventually reach a breaking point, after which the energy harvested from piezoelectric sources would be greater than that of energy consumed from natural gas. Although this may not be in the near future (a precise calculation of the break-even year would be especially difficult to calculate since there are so many parameters that are quite unpredictable), there is a promising probability for it to occur, provided that there is a well-funded and appropriately planned implementation of piezoelectric sources in Cairo. Additionally, based on the increasing trend of energy harvested from piezoelectric sources, the energy harvested in 2020(1.441×10^9 kWh) suffices the need(in 2020) of not only the city of Cairo, or the country of Egypt, but satisfies the aggregate need of 14 countries in the world (Samoa, Vanuatu, Saint Vincent and the Grenadines, Tonga, Sao Tome and Principe, Sierra Leone, Solomon Islands, Nauru, Saint Kitts and Nevis, Comoros, Kiribati, Guinea Bissau, Dominica, and Central African Republic) with 139 GWh of electricity left to spare.

Power Infrastructures consist of the facilities which generate, transmit and disseminate energy and power. Modern day power infrastructures cater mainly to non-renewable methods of energy production such as nuclear, oil, natural gas and fossil fuels. In order to utilize these sources of energy, massive power plants must be built. Not only do these power plants themselves require massive amounts of funding and create enormous amounts of pollution (*Mishra ;2004*) and incur other consequent environmental effects (deforestation, loss of habitat, extinction of species), but also require a lot of time before they become operational. This shows that the negative costs arising from the production of energy through non-renewable means has severe long term negative consequences. On the other hand, Piezoelectricity can simply be generated by placing the device wherever there is a change in pressure or stress. There are much smaller damages and costs of building and the primary drawback is the pollution generated in manufacturing the device- a consequence that can be eliminated in the long term as you can eventually power the factory itself by piezoelectricity (say by lining the floor with the device). This makes the application of piezoelectricity a cycle; initially, it is dependent on other sources of energy. Eventually, it can be made fully self-sustainable. Highlighting the future potential of piezoelectricity, it can be seen that current power infrastructures will be replaced by piezoelectricity and other renewable forms of energy. While this process of conversion may not happen in a short period of time due to the current necessity and heavy reliance on non-renewable resources, over the long-term there will be a gradual but non-negligible shift towards piezoelectricity and other forms of renewable, organic and clean sources of energy.

The animal kingdom has seen a lot of changes due to global warming and climate changes. It is estimated that over 50 different types of cetaceans have become endangered solely due to Global Warming (*Simmonds et al., 2009*) and that global warming influences changing disease dynamics leading to extinction (*Alan Pounds et al., 2006*). For the perusal of this paper, the impact of climate change, before and after implementing piezoelectricity, on the spotted hyena will be considered. It is well known that spotted hyena's have had declines in population due to climate change and global warming (*Bhandari et al., 2022*) and that declines in the abundance of populations in the African regions have also been demonstrated *(Jones et al., 2021).* This occurs as a consequence of increased competition, reduced prey density (as a result of lower precipitation) and arid conditions. (*Jones et al., 2021*). However, by implementing Piezoelectricity in only these 3 scenarios, the African continent's average temperature would have been lower by 0.1C and 15 years in the future the temperature increase would only be 1.7C-1.9C and not the forecasted 2C (*Yerlikaya et al., 2020*). This would significantly boost Hyena's current and forecasted population densities(by preventing their population decrease). Furthermore, although 2 degrees celsius does not seem substantial, it could lead to a fall in agricultural yield, cause hundreds of millions of people to starve, displace millions due to rising seawater levels, cause the Arctic, Antarctic and Amazonian ecosystems to collapse and elicit forests and grasslands to disappear among other devastating implications (*Warren et al.,2006*). Therefore, it highlights the urgent need of implementation of other forms of renewable energy such as piezoelectricity.

On the other hand, certain subsets of species such as cephalopods have been benefited by Global Warming through increased population recruitment and their population dynamic has seen a Northward trend (*Rodhouse et al., 2014).* But the movement of their habitat can have disadvantageous effects on their previous habitats and lead to negative change in the ecosystem and fisheries around the Mediterranean (*Schickele et al., 2021*).

Further Considerations

Ethics

The substance used at the core of the piezoelectric device - the quartz crystal - is mostly obtained through mining. This leads to ethical considerations for the miners (rock drillers) as overexposure of gold mine dust (which generally contains 30% of quartz and where quartz is normally mined from) is a large contributor to pneumoconiosis and other lung diseases (*Kemsley, Daniel Michel,. 2009).* This can be solved through administrative controls ensuring appropriate, correct and maintained use of Respiratory Protective Equipment (RPE's) (*Kemsley, Daniel Michel,. 2009*) which thereby solves the only major ethical consideration of the piezoelectric device.

Structural Cost

Compared to building a new fossil fuel based or nuclear based power plant, implementing piezoelectricity is much cheaper because aside from placing the piezoelectric device and connecting it to a power grid, no other installation or foundation is required. Each device per square foot costs 380 dollars using a quartz based Piezoelectric system without taking advantage of economies of scale. Additionally, the device need not be placed throughout the area, but can be placed in locations of high pressure or frequent changes of pressure (at the entrance of places with high foot traffic, elevators etc.). Furthermore, if the quartz crystal is replaced with other piezoelectric materials such as Nanocellulose and Chitosan, the cost can be reduced further (*Hänninen et al., 2018*).

Feasibility

Taking the example of Elshohadaa station is Cairo, its daily requirements of energy are 10MW and foot traffic is 150,000 people a day. Utilizing other existing piezoelectric tiles/devices such as Pavagen, SEF and Waynergy, only 14 Pavagen tiles, 10 SEF tiles or 7 Waynergy tiles would be required to completely power the station if placed in the places of high-density foot traffic which were considered by analyzing densities of pedestrian disruption (Elhawagy et al,. 2017) . This makes the entire station self-sufficient only by its footfalls and if there were a possibility to place more tiles, there would be an excess of energy which could be routed to external areas. The cost of using Pavagen for the 14 tiles is 26,116 USD, SEF for the 10 tiles is 7,995 USD, and Waynergy for the 7 tiles is 1,492 USD. Furthermore, the lifespan of the 3 ranges between 15-20 years making the piezoelectric tiles highly implementable. Hence, due to the simplicity of its production and implementation, high daily power output and efficiency, low cost, high durability, and environmental benefits, piezoelectricity is a highly feasible and a readily implementable option of energy.

Future Implications

As mentioned before, the piezoelectric device can be applied in virtually any instance involving a change of pressure giving it high applicability. The largest areas of application are currently the industrial, manufacturing and automotive industries (Kumar, Priyanshu ,. 2013) but it can also be utilized on a large scale in structural, biomedical, implantable electronics, water and smart system industries on a nano, micro and mesoscale (Sezer et al.,2021). This depicts that there are a variety of methods in which, using piezoelectricity, energy can be harvested; this supporting the gradual shift to piezoelectricity as a primary source of energy. Furthermore, research at Carnegie Mellon University expands the versatility of piezoelectricity by showing that the energy created by the vibrations of the piezoelectric device can be constructed by passing sound waves through the device (Liu M.L ., 2019). This opens up the industries and fields of utilization of piezoelectricity.

Conclusion

This paper's primary purpose was to model and examine the impact of piezoelectricity on temperature and Carbon Emissions, and evaluate its consequent benefits and feasibility of implementation if utilized in bus tires, train tracks and stations. By evaluating all of the above, the importance of substituting to a cleaner energy source and the benefits that piezoelectricity could play as an energy source can be further understood. The results show that the energy consumed from natural gas, the hottest temperature in June, and the CO2 emissions would all decrease. These changes would slow down habitat destruction and prevent the extinction of various species from the animal kingdom. Furthermore, the costs of building power plants would reduce, since there is a gradual shift towards self-sustainable piezoelectric-plants. The high applicability of piezoelectricity makes it useful in diverse industries from which energy can be generated. Its low cost, long-term lifespan allows the transition to piezoelectricity to be smooth and economical; the saved funding could be used to develop other areas of infrastructure. Moreover, although this paper utilized various assumptions for the sake of simplicity, the results do support the claim that even a gradual shift towards piezoelectricity (or any renewable energy source) can have substantially positive effects in the long run.

Limitations

Some compromises in accuracy were made to simplify the process of calculation for the forecasted temperature. They stem from the lack of available data leading to approximations in the formulae of the 3 scenarios. Even a small difference in the final temperature reading can have large implications for the Earth's ecosystem, but, due to the variables having a small margin of error, the change in reading is negligible for the aim of this paper.

Acknowledgements

We would like to thank Mr. Mandar Tulankar, whose guidance and feedback have been invaluable in our exploration of piezoelectricity’s applicability.

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