An Automated GIS based Piezoelectric Potential Assessment: PE Calculator©

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Abstract –

Renewable Sources are at the front line of policy discussions for replacing the fossil fuels around the world. Piezoelectric (PE) material can generate electricity in response to mechanical stress. Knowing that cars put a significant amount of stress onto the roadways every day, the use of piezoelectric transducer for asphalt pavement energy harvesting has gained the attention of researchers in the recent years. Despite the continuing research on improving the efficiency of this new technology, developing a tool to measure the PE potential of the roads, is a necessity for future utilization of piezoelectric materials. Addressing such a need, in this research, we use the python programming language, the scripting language of choice for the ArcGIS platform, to develop a state of the art software – PE Calculator© - which generates the PE potential of roads. The PE Calculator© gives the user the choice of defining the boundary of study, traffic condition and PE coefficient. In addition to visualized PE potential maps using Geographies Information System (GIS), the PE Calculator© generates a detailed table, expressing the PE potential for each road segment. The result of this research can be used by both public and private sectors, including policy makers, transportation engineers, city planners, and etc. to prioritize future PE implementation plans accordingly.

Keywords –

Piezoelectric potential; Python; Geographic Information System (GIS); Energy

1. Introduction

The current need for energy and its increasing consumption trend across the countries in the world encourage researchers to search for a new renewable source of energy. Such an alternative source of energy not only contribute to addressing the issue of scarcity of fossil fuel in the future, but also would have minimal negative impact on the environment. The Piezoelectric (PE) ceramics are an example of such efforts. PE ceramics can transform mechanical impact energy into electrical power [1] [2] [3] [4] [5]. During the past decade, the traffic on the roads in the US have intensely increased, causing several issues, including congestion, which results in waste a massive amount of time, money, and fuel [6]. However, the traffic may not always cause negative consequences. Some previous research focus on the feasibility and efficiency of piezoelectric transducers for the purpose of generating electricity, in form of asphalt pavement energy harvesting [7] [8]. Placing the PE devices five centimetres below the asphalt surface, can generate electricity as the pressure caused by running vehicles would slightly deform the piezoelectric crystals [9]. In 2011, California state assemblyman Mike Gatto proposed Assembly Bill 306 to develop this technology for Californian roads [10]. Although, several research has been conducted on the topic of PE energy generation via pavements on the roads, estimating the energy that can be generated by such a technology, if implemented in a metropolitan area, within any given boundary has not been done to this date. The high sensitivity of PE technology on the road to the traffic level, at each given road, adds additional complexity to the calculation of energy generation. The analysis of energy generation, also highly depends on the type and location of the road/s, where we implement the PE system, as the traffic load varies for each road. The Geographic Information System (GIS) can provide a perfect mean to extract such information in any given scale, from one block to a whole neighbourhood in a city, and even an entire metropolitan area. However, calculating the energy generation using PE, would be a time consuming process and even impossible, as we increase the scope of study. In this research, we develop a state of the art software, PE Calculator©, which is compatible with a GIS program to read the input data from, in addition to the data that user can directly insert through its user friendly interface, and generate the result both in visual format (map) and more detailed version (table). The PE Calculator can be used by policy makers, researchers, city planners, and investors who want to assess the different scenarios for implementing the PE technology on the urban roads. In this research, we limit the scope of PE Calculator the boundaries of the Atlanta metropolitan area, Georgia. However, the PE Calculator can expand its limit to any extend to which the road system network and historical traffic information would be available.

This paper is organized as follows: section 2 describes the method we used for developing the PE Calculator. In section 3, we explain in detail, how the PE Calculator computes the potential energy that the PE technology can generate. Section 4 provides a numerical case example, which we use the PE Calculator to assess the energy potential using PE technology on the road, for two separate neighbourhoods in the Atlanta. Finally, the conclusion is discussed in section 5.

2. Methodology

We consider some assumptions for the calculation of the PE energy potential which are discussed in more detail in this section. Hill and Tong (2013) summarized the recent progress on PE technology, especially focusing on the recent studies on its conversion efficiency from stress to electricity. Assuming that PE materials will be install underneath the roadway to absorb the mechanical stress caused by the passing vehicles, we used the result of previous research on PE technology in the past to calculated the conversion factor which is about 0.0267 kWhr/year/feet/lane for average weighted passenger cars [8] [11]. The total PE energy potential is then a function of the conversion factor, length of the road, and the number of cars running on these roads.

We acquire a detailed road network shapefile in Georgia from TIGER on Census website, which contains not only the shape, length, and number of lanes of each road, but also the classifications of each road segment. After examining the current road network in Georgia, we found that highways, ramps, secondary roads and local roads made up about 97% of all roads in the TIGER shapefile (Table 1). Thus we only use those four road types in the PE Calculator© at this research.

Table 1 – PE Calculator road coverage

Road ID	Description	# of Lane	Proportion of Total
S1100	Highway	8	1.25%
S1200	Secondary Roads	4	6.74%
S1400	Local Roads	2	88.05%
S1630	Ramps to HWY	1.5	0.93%
		Sum	96.97%

To account for the different daily traffic at each road type, we construct different baseline traffic conditions for each of these four toad types. For instance, we define a medium traffic level on highway to be 30,000 vehicle/day, while the medium traffic level for secondary road beings at 3,000. All these numbers are average approximations, based on Georgia Department of Transportation's (GDOT's) annual average daily traffic number [1].

We also incorporate ArcGIS into our PE Calculator. While Python GUI was chosen to build our user interface and the calculation module, we used ArcGIS to deliver the calculation results, due to its capability of generating an easy to read maps, with multiple layers.

3. PE Calculator© – State of the Art software

The goal of our work was to develop a software, compatible with a GIS model, which can assess the potential electricity that could be generated by PE technology on the roads. The PE Calculator© is a standalone software and though its interactive capability with the ArcGIS software makes it possible to read data generated by ArcGIS, such as the shapefile for the study boundaries (defined by the user). The software also generates results in visualized format that can be read by ArcGIS software. The PE calculator analyzes the specification of each road, takes into account the traffic level, and computes the energy potential generated by the embedded PE technology on a road network, based on the PE density coefficient defined by the user. Addition data were predefined and loaded into the software during the development stage.

Figure 1 shows the flowchart of how the PE Calculator computes the energy potential by PE technology on the road. The PE Calculator uses three layers of inputs. We follow two principles for the development of the PE Calculator: simplicity in terms of getting only the necessary information from the user, and accuracy which we only used the data from the official governmental sectors such as Department of Transportation (DOT), or reputable resources such as Google map. We used three layers of data in PE Calculator©:

1- The first layer of input data can be provided by the user through ArcGIS. The user, through the ArcGIS software, defines the boundaries for the energy calculation. This boundary can be as small as one section of a street, or as large as the Atlanta metropolitan area. The PE Calculator then extracts the streets and street types within that boundary, through its pre-saved street network TIGER database.

2- The second layer of input data is gotten directly from the user, via the PE Calculator's User Interface (UI).

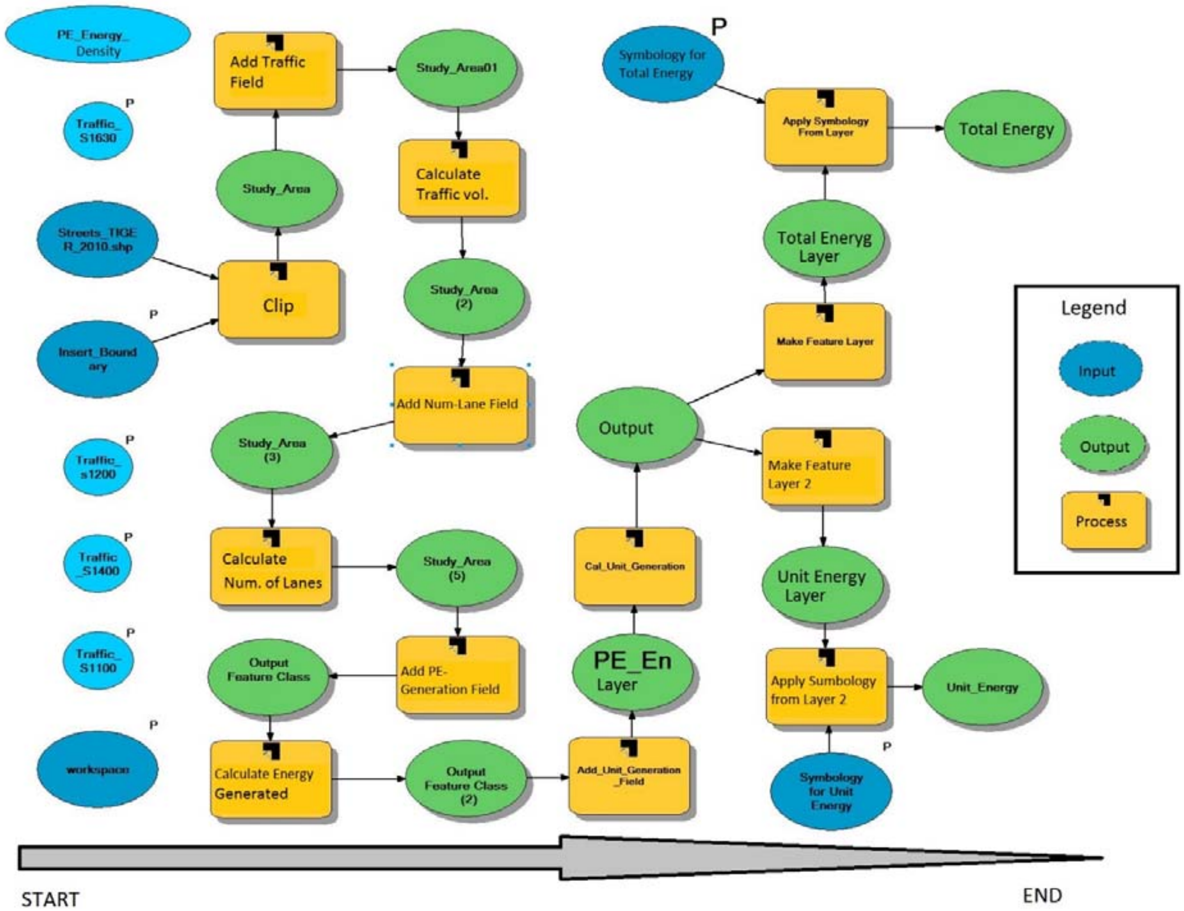

Figure 1. PE Calculator Flowchart.

These data are either necessary to be gained via user, such as the traffic level (high, medium, and low) for the assessment purpose, or can be changed through time such as PE coefficient, which can change as the technology advances. Although we preload the traffic information on each road type from GDOT's Geo-counting website [1]. Here, we provide an extra level of customizability into our software, for the user to investigate the energy that can be generated at different level of traffic.

3- The third layer of input data are those that were preloaded into the software, such as the street network of the Atlanta metropolitan area. These data are either fixed or do not change in a short time span.The PE calculator computes the energy generated by the PE system on the roads, and generates the result, in two formats: map and table. Using the map, the user can visualize the energy generated by the PE within different sections of predefined boundaries. The table provides a more detailed information for the user, such as the exact amount of potential energy, each road segment within the given boundary can generate.

We developed the PE Calculator, using Python programming language. User Interface (UI) of the PE Calculator is simple, while it gets all the required information from a user. Figure 2 shows the UI of the PE Calculator©.

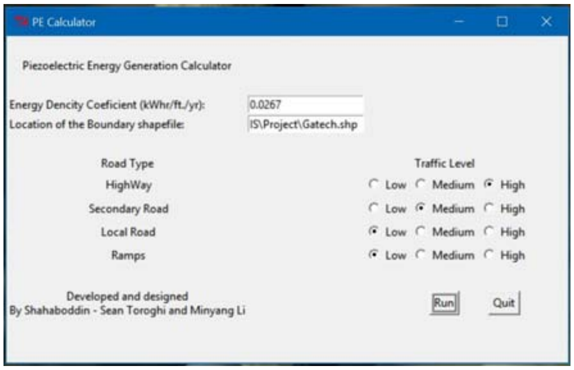

Figure 2. PE Calculator User Interface.

The simple UI provides the user an easy and intuitive environment to enter the inputs. More specifically, user can enter the PE energy conversion factor. As the PE technology advances through time, the efficiency of it can change as well. The user can also enter the location of the saved boundary shapefile on the hard drive of the computer that was created in the past, using any version of ArcGIS software. The traffic level section will take user inputs on the traffic level of different road types. The user will be able to investigate the impact of different traffic levels on energy potential on the roadways. There are three traffic level, Low, Medium, and High, for each of the four road types: Highway, Secondary Roads, Local Roads, and Ramps.

Once the user clicks the Run button, the PE Calculator© computes the PE energy potential on the roadways within the boundaries, and generates and saves the results as the output. The output of the software is in the form of maps and tables, which have the attributes of the energy potential generated by the PE, on different unit scales. The maps are in shapefile format, which can easily read or printed out by the ArcGIS software. Moreover, the shape file provides a unique capability for the user to include or exclude parts if the computed information, based on the desire point of focus. In the next section, we explain in more detail how the PE Calculator© can be beneficial for both public and private sectors, by presenting two case studies, for two neighborhoods in the Atlanta metropolitan area, followed by a comparison and discussion parts.

4. Case Study

In this section we present two case studies, to illustrate the benefits of using our PE Calculator© Software. The first case study illustrates the software's capability to be used in scenario planning: By selecting different traffic level across the four predefined road types in the software, users will be able to get an accurate output that better represent the real world traffic. The second case study focus on the software's ability in performing analysis on multiple boundaries. Such feature enables the users to easily compare the total PE energy potential across different geographic boundaries.

4.1. Case Study 1: Using the Software for Scenario Planning

In the first case study, we firstly create a boundary shapefile for our study area in ArcMap, as shown in Figure 3 below.

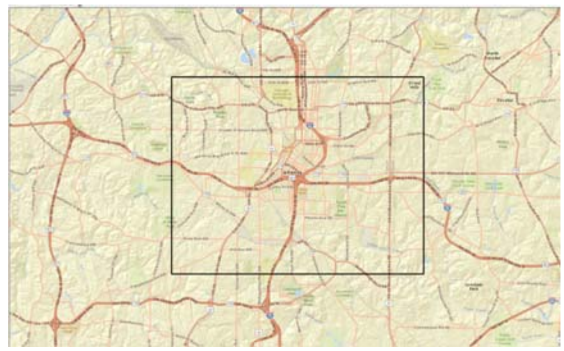

Figure 3. Study Area Boundary.

We first examine the PE energy potential per feet under the scenario that all four predefined road types are experiencing high level of traffic in this study area (Figure 4). The output of unit PE energy potential are exhibit at Figure 5.

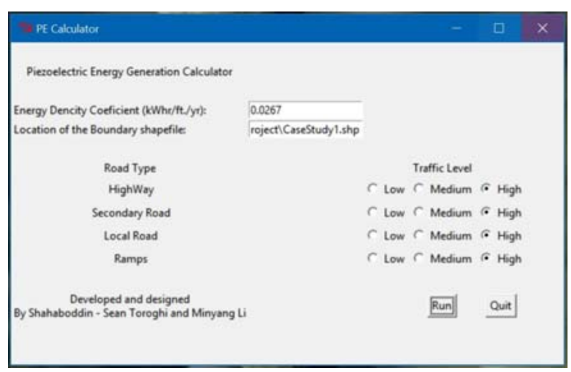

Figure 4. High level of traffic on all four roads in the study area.

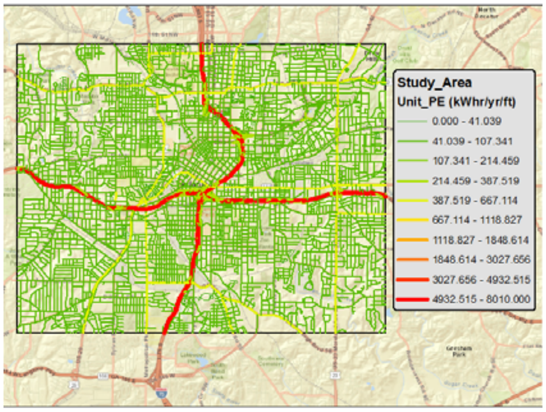

Figure 5. High level of traffic on all four types of roads in the study area.

We then changed the traffic level on highways and ramps from high to low, as shown in Figure 6, while keeping the traffic level on other roads constant. Result is shown in Figure 7.

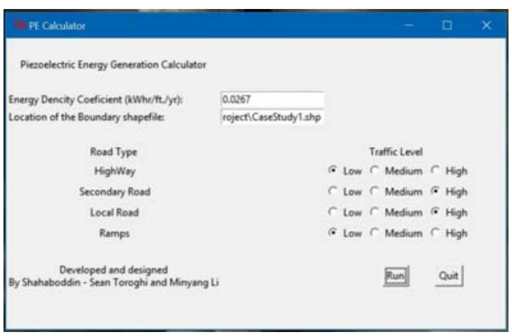

Figure 6. Changing to low traffic level on highways and ramps in the study area.

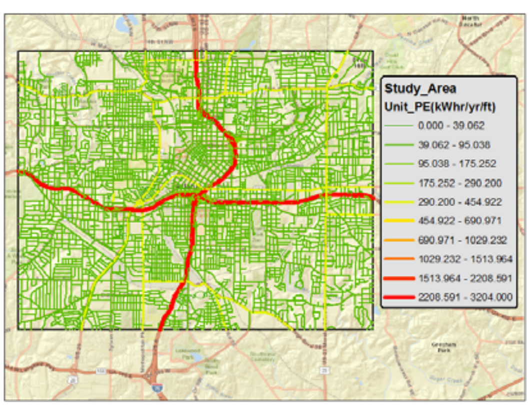

Figure 7. High level of traffic on Secondary and Local Road, Low level of traffic on Highway and Ramps in the study area.

Users can notice the changes in the legends and the consistency in the overall symbology of the output. Our software will automatically adjust the legend according to calculation results. Combining the unified symbology feature with its ability to adjust the traffic level across four pre-defined road types according to real world traffic, the PE Calculator© facilitate the process of analyzing different scenarios for planning purposes.

4.2. Case Study 2

In the second case study, we focus on the PE Calculator's ability to perform analysis on multiple areas simultaneously. The study area consists of two rectangles with the same dimension, as shown in Figure 8 below. The upper rectangle represents Georgia Tech (GT) Campus area, while the lower one represents the Downtown Atlanta.

Figure 8.Study area consists of two areas. Upper rectangle being GT campus, and the lower one being Downtown Atlanta.

Using the mentioned two boundaries, we run the PE Calculator© using the boundary shapefile. For demonstration purposes, we selected high level of traffic on all of the predefined road types. The output is shown in Figure 9.

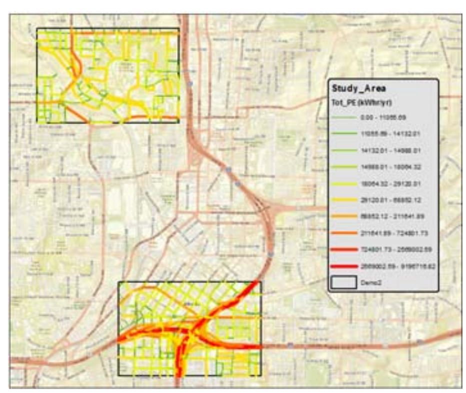

Figure 9.Downtown Atlanta have a higher PE energy potential compared to GT campus

The differences (the red, yellow, and green colors) in potential energy generation can be seen in figure 9, where the Downtown Atlanta has a higher total PE energy potential compared with GT campus area. In fact, PE Calculator also provides the total PE energy potential for each of the areas in the output tables: Downtown Atlanta has about 20 times as much PE energy potential as GT campus. The vast difference is largely due to the different traffic volume on a daily basis, which the PE Calculator© took into account. Downtown Atlanta has a much larger traffic volume, in comparison with the campus area. This unique feature enables the user to easily compare the benefits of implementing the PE technique in different areas side by side, leading to more informed decisions.

The two case studies illustrate how our software, PE Calculator, is capable to perform automatic calculations at different scenarios considering different traffic levels within multiple study areas. Such features of the PE Calculator© software give it an edge compared to other manual or semi-automatic methods in estimating the PE energy potential on roadways.

5. Acknowledgements

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6. Conclusion

Piezoelectric technology opens a new door to scientists and researcher searching for new sources of clean energy. The Piezoelectric (PE) material can transform the mechanical energy to electricity. This technology has already passed the preliminary stage. The use of PE technology inside the road pavement can result in generating electricity, when vehicles move on the road. The viability study shows the vendor-based levelized cost of energy (LCOE) in average is $0.11 /KWh [11]. Although the PE technology shows a promising future in energy harvesting, assess the energy generation in a large scale (neighborhood, city, and etc.) can be too complex and time consuming. Furthermore, for the purpose of comparison of energy harvesting using PE in pavement, researcher and investors would need to take into account other factors that influence the PE energy generation potential, such as traffic level. In this article, we introduce the PE Calculator©, a state-of-art software that is capable of performing automatic calculation of PE energy potential on roadways and generate meaningful and appealing visualizations in ArcGIS. Key features of the software include its ability to incorporate variations in user inputs, assess PE energy potential within the study area, according to the user inputs, and perform the calculation simultaneously on multiple study areas. Such features give it an edge compared to other manual or semi-automatic methods in estimating the PE energy potential on roadways. Potential users from multiple fields, such as scientist working on improving PE technology, city planners, policy makers, traffic engineers, and investment companies, will all benefit from incorporating PE Calculator ©, an easy to use, comprehensive and accurate software for computing the energy potential of PE technology on the roads.

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