CHAPTER 1
INTRODUCTION

1.1 Background

Global energy consumption has increased significantly due to population growth and industrial activities (Sari & Sari, 2025). Modern society is highly dependent on electrical energy, while fossil fuel reserves are continuously depleting due to their non-renewable nature. This condition has driven the exploration of more sustainable alternative energy sources. Various natural resources have been utilized to meet electricity demands (Ekawita et al., 2021), highlighting the importance of developing environmentally friendly energy alternatives. The growing dependence on fossil fuels has led to adverse environmental impacts; therefore, strategic solutions to address the energy crisis include the utilization of alternative energy sources such as solar, wind (Alim et al., 2023), and mechanical energy (Nugraha & Buchori, 2022). The implementation of alternative energy systems can be carried out not only on a large scale but also on a small scale by harnessing mechanical energy from daily activities. In addition, the concept of energy harvesting (Mou et al., 2025) from the surrounding environment, such as traffic density, represents a promising approach that can contribute significantly to sustainable energy supply. Daily traffic generates substantial mechanical energy from vehicle movement on roadways. Speedbumps widely installed in Indonesia present considerable potential for mechanical energy utilization. Each vehicle passing over a speedbump undergoes rapid deceleration, producing mechanical stress that can be converted into electrical energy using piezoelectric sensors. In strategic locations with high traffic density, a single speedbump may be traversed by thousands of vehicles per day, thereby offering significant potential for electrical energy generation.

Piezoelectric sensors have emerged as a promising alternative for converting mechanical energy into electrical energy in speedbump applications. Piezoelectric materials are crystalline structures capable of generating electrical energy when subjected to mechanical stress. The piezoelectric effect is classified into two types: the direct piezoelectric effect, in which an electrical potential difference is generated in response to applied mechanical force, and the converse piezoelectric effect, where the application of an electric voltage induces mechanical deformation (dimensional change). Under mechanical stress, the charge distribution within the piezoelectric material becomes aligned, resulting in the formation of positive and negative occurs more rapidly, and the separation of charges leads to the generation of an electrical potential. The voltage produced by a piezoelectric sensor can reach several volts, depending on the material type, sensor dimensions, and the magnitude of the applied pressure (Kallawa et al., 2022).

Oil palm empty fruit bunches (OPEFB) possess material characteristics that are highly potential for conversion into carbon-based materials, with cellulose, hemicellulose, and lignin contents of 36.81%, 27.01%, and 15.07%, respectively (Anindita et al., 2024). Natural Carbon Dots (CDs) exhibit excellent fluorescence properties, nanoscale size, and high biocompatibility. CDs doped with metal elements such as Zn have attracted considerable attention due to their enhanced functionality. The doping process significantly modifies the physicochemical properties of CDs, leading to improvements in fluorescence intensity, band gap energy, electrical conductivity, and photocatalytic activity. Furthermore, doped CDs demonstrate enhanced electron transfer and electron-accepting capabilities (Amirsoleimani et al., 2025).

Various previous studies have demonstrated the potential of piezoelectric sensors for electrical energy generation. Sidiq dkk., 2021, designed a speedbump prototype integrated with piezoelectric sensors, achieving a maximum output voltage of 17.88 V and an average power of 2.9 W. Pratama dkk., 2022, reported that piezoelectric sensors effectively convert mechanical energy from vehicles passing over speedbumps into electrical energy, utilizing a series and parallel circuit configuration to optimize the output. In more specific applications, Apriyanto dkk., 2021showed that piezoelectric sensors installed on stair steps can harvest energy with a maximum output of 297.4 µJ. Valemtina dkk., 2025, developed a piezoelectric-based foot mat prototype capable of generating electrical energy and successfully powering an LED with a maximum voltage of 7.17 V. In the context of CDs, Dona dkk., 2021 synthesized CDs from natural precursors, namely OPEFB. However, most previous studies have primarily focused on optimizing piezoelectric sensor circuit configurations and evaluating energy output across various applications. To date, there has been no investigation on the application of CDs as a coating layer on piezoelectric sensors. Theoretically, Zn-doped CDs are promising for such applications due to their physicochemical properties, which contribute to enhanced electrical conductivity, improved electron transfer, and increased electron-accepting capability.

Therefore, this study aims to develop a piezoelectric sensor integrated into a speedbump by applying synthesized Zn-doped CDs derived from OPEFB as a coating layer on the sensor surface, with the objective of enhancing its mechanical performance for electrical energy generation. The Zn doping of CDs will be carried out using the sol-gel method, followed by characterization using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and UV-Vis Spectroscopy. The piezoelectric sensor coated with Zn-doped CDs will then be subjected to mechanical loading tests with varying loads to evaluate the resulting voltage and current outputs under different applied pressures, using a multimeter as the measurement instrument.

1.2 Problem Formulation

1. How does load variation affect the output performance of the piezoelectric sensor?
2. How do parallel and series circuit configurations influence the performance of the piezoelectric sensor?
3. How effective is the synthesized CDs coating derived from OPEFB doped with Zn in enhancing the mechanical performance of the piezoelectric sensor?

1.3 Research Objectives

1. To analyze the effect of load variation on the output performance of the piezoelectric sensor.
2. To compare the performance of parallel and series circuit configurations in the piezoelectric sensor.

3. To evaluate the effectiveness of synthesized CDs derived from OPEFB doped with Zn as a coating layer on the piezoelectric sensor in improving its mechanical performance.

1.4 Research Benefits

1. To provide guidelines for determining the optimal load to achieve maximum output from the piezoelectric sensor.
2. To identify the optimal circuit configuration that can be applied in the design of piezoelectric sensors to maximize output performance.
3. To develop an innovative sensor coating material utilizing Zn-doped CDs derived from OPEFB.

1.5 Hypothesis

1. The applied load significantly influences the output capacity of the piezoelectric sensor. As the mechanical load increases, the generated voltage also increases, resulting in a substantial enhancement of the output.
2. A parallel circuit configuration in piezoelectric sensors produces a higher output current with relatively constant voltage, whereas a series configuration yields a higher output voltage with relatively constant current.
3. The application of Zn-doped CDs derived from OPEFB as a coating on the surface of the piezoelectric sensor can promote a more uniform distribution of mechanical stress and enhance the overall output performance of the sensor.