

**THE REPUBLIC OF TURKEY  
İSTANBUL KÜLTÜR UNIVERSITY  
INSTITUTE OF GRADUATE STUDIES**

**ANALYSIS OF AMBIENT ENERGY HARVESTING IN INDIVIDUAL  
AND INDUSTRIAL ENVIRONMENTS USING QUANTITATIVE  
METHODS**

**MASTER OF SCIENCE THESIS**

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**Department: Industrial Engineering**

**Program: Engineering Management**

**Supervisor: Prof. Ayşe Tülin AKTİN**

**February 2023**

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Date: 23 January 2023

Sehrish Razzaq Shah



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## LIST OF SYMBOLS

MEMS	Microelectromechanical Systems
kWh	Kilowatt Hour
AC	Alternating Current
DC	Direct Current
EMfit	Electromagnetic Fit Sensor
RE	Renewable Energy
BEPE	Break-Even Price of Energy
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
LCOE	Levelized Cost of Energy

**Üniversite** : İstanbul Kültür Üniversitesi  
**Enstitü** : Lisansüstü Eğitim Enstitüsü  
**Anabilim Dalı** : Endüstri Mühendisliği  
**Programı** : Mühendislik Yönetimi  
**Tez Danışmanı** : Prof. Dr. Ayşe Tülin AKTİN  
**Tez Türü ve Tarihi** : Yüksek Lisans – Şubat 2023

## ÖZET

### **Kantitatif Yöntemler Kullanarak Bireysel ve Endüstriyel Ortamlarda Ortam Enerjisi Toplama Analizi**

**Sehrish Razzaq Shah**

Ortam Enerjisi hasadı, bir enerji türünü üreten veya başka bir enerji biçimine dönüştüren bu tür bir kaynaktan enerji toplamanın ve öğütmenin bir yoludur. Ancak bu enerjinin yanı sıra, günlük veya yoğun rutinizde kimsenin farkına bile varmadığı enerjinin bir kısmı da kaybedilmekte ve israf edilmektedir. Bu, bizim veya makinelerin kinetik enerjisi olarak bilinen bir enerji türüdür. Bu küçük miktarı hasat ederek, belirli bir alet seti ile kontrol etmek ve yüzyıllardır benimsediğimiz pahalı yöntemler yerine günlük kullanımlarda yararlanmak üzere büyötmek mümkündür. Bu vaka çalışması, çevresel enerji hasadının bireysel çevrede nasıl önemli bir rol oynadığının bazı yönlerine ve bunun yanı sıra, yolumuzdaki bu enerji kullanımını ile başa çıkmak için endüstriyel sektörün hangi gelişmelere sahip olabileceğine odaklanıyor. Böylece sanayinin, bireysel ve şirketlerin kullanım giderlerinin büyük bir kısmını oluşturan konvansiyonel ve pahalı enerjiye bel bağlamadan, kendi enerjisini üretmeye başlayacak duruma gelmesinin yolu açılmış oluyor. Sonuç olarak, daha az kirli ve tüm toplum için karşılanabilir olan, kendi kendine çalışan evler ve endüstrilerle bir gelecek yaratabileceğiz.

**Anahtar Kelimeler:** Ortam Enerjisi, Hasat, Kendi Kendine Çalışan

**University** : İstanbul Kültür University  
**Institute** : Institute of Graduate Studies  
**Department** : Industrial Engineering  
**Program** : Engineering Management  
**Supervisor** : Prof. Ayşe Tülin AKTİN  
**Degree Awarded and Date** : MS – February 2023

## **ABSTRACT**

### **Analysis of Ambient Energy Harvesting in Individual and Industrial Environments Using Quantitative Methods**

**Sehrish Razzaq Shah**

Ambient Energy harvesting is a way to reap and grind energy from such source which is producing or converting one form of energy into another, but alongside that energy some of the energy is being lost which in our daily or busy routine no one even notices that something is being wasted. That something is known as our or machines kinetic energy which even we ourselves cannot recognize. That small amount is harvested and then controlled with some specific tools set and magnified to be get used in daily uses instead of those expensive ways which we have adopted from centuries. This case study is focusing on some aspects of how ambient energy harvesting is playing an important role in individual environment as well as which development we can have for industrial sector to cope up with this energy utilization hinge in our way. Also, we have laid a way to make our industrial sector that sufficient that it will start generating the energy on its own and not to rely on conventional and expensive energy, which has grasped the major portion of individual and companies' utility expenses. By the end we will be able to create a future with self-powered homes and industries that will be less polluted and affordable to all the community.

**Keywords:** Ambient Energy, Harvesting, Self-powered

# 1. INTRODUCTION

Energy harvesting is the course of cultivating the energy from ambient sources which no one is paying attention to, because of their small size and negligible amount. So, to utilize those small amounts and cascade them in such a way that they can give us a huge and continuous impact for almost unlimited period. This feature of energy harvesting made them the most promising emerging sources of green energy.

Ultimately in this study we are working on two sectors to apply our fundamental technique. Which is what we are implying to cultivate the energy for Individual and industrial level environments.

This level or scale is majorly focusing on benefits and energy demands of a personal level or we can cultivate the energy for an individual. A study on energy consumption in 2019 found that the average daily energy consumption for an individual in India is 19 kWh. China, on the other hand, consumes 75 kWh per day per person, which is above the global average. In the coming decades, China's energy consumption is expected to match that of industrialized nations. In 2019, the total primary energy consumption worldwide was 13.9 billion tons, with a population of 7.7 billion, resulting in a global average of 58 kWh per day per person. So, keeping in view these facts and figures energy needs must have to be met on a higher scale and it also must have to be such a source which can never be depleted. This study is focusing on making energy of self-cultivating basis which is quiet independent way of harvesting the energy. The technique involves our daily basis movements on normal routine and converts them into another form of energy which is certainly be the electrical energy. The components primarily be used by in this research would be transducers (mechanical to electrical) mainly and widely to be called as piezo crystals, stretchable wire/cables and sensors. These devices can be used depending upon the scale of harvesting.

This case study is engrossed on providing the procedures which will be the key turning point in the industrial and individual sector for the utilization and consumption of the energy, which is not running out, as soon as it has been instigated or installed. It will make us comprehend that how we can have self-powered industries in the future

to deal and cope up with the current situation of high and costly prices of the energy and its high end and expensive generation procedures. The main argument and intention of resounding out this research is to deal and find explanations for the hitches which are too common to be think of at standard or grass root level.

- Increasing energy needs in this era for individual and industrial environment.
- Prices and affordability of energy which is increasing on alarming rate and tends to keep up the rate.

These are two communal and most unreciprocated and under-rated problems that exists around all of us, but regrettably, everyone has crooked their eyes on these matters and agree to take the situations by compensating expensive bills and utilities. The answer to these communal problems has been researched and discussed in this study thoroughly with their methodologies and implementation details (Ewart, 1999).

The study is organized as follows: Section 2 presents the relevant literature review. Implementation instances and quantitative analysis are explained in Sections 3 and 4, respectively. Section 5 concludes the study and states some recommendations.

## 2. LITERATURE REVIEW

Energy has been the point of ponder since the human race began to encroach in the field of technology and started to place footsteps in different technological areas. Therefore, with the course of time, increasing population and growing needs of the humans made the energy to be the crucial inevitability of today's world. The truth is that from some of the past years, human race is being pugnacious with each other to acquire these energy resources. These conflicts over the time got that much bigger that most of the countries, researchers and physicians/scientists are now forced to think about the ways and ideas of getting self-sufficient with energy resources which cannot be stolen by anyone and also those of the energy resources are going to be limitless and renewable. Former research in power electronics on piezoelectric crystals and kinetic energy has shown that it can be used as an energy resource. This research and the rise in the need to obtain energy supplies in today's world constitute the main motivation of the current study on energy harvesting (Erturk & Inman, 2011).

The drive of this effort is to put some focuses on how those renewable energy or ambient resources are creating impressions on the individual and industrial levels. As mostly, the countries are relying on their industries and progressing using those industries and for that sake, they invest a lot of money in providing their industries with the non-stoppable energy. Energy as for today's concern is the topmost item in the checklist whenever anyone is moving to some place, or any big investor is looking to setup any industry. So how this ambient energy harvesting is helping us out on individual and industrial levels and making a big difference with such a small amount of it being utilized with an infinity factor and without fear of being depleted will be analyzed. As technology advances, the need for powerful and long-lasting power sources for wireless sensors, implantable electronics, and wearable devices is becoming more pressing. Energy harvesting, which uses sources other than batteries, is emerging as a potential solution for powering these low-power devices. The piezoelectric effect, which converts mechanical energy into electrical energy, is being widely studied due to its high efficiency, ease of implementation, and potential for miniaturization (Yang et al., 2018). Essentially energy harvesting is ultimately the course of the excavating the energy from such sources which are being squandered in

our daily routine while walking, sitting, typing on our laptop and when it comes to industrial or bigger level so whenever a big machine or equipment is being used like gigantic generator, heavy duty cargo machines, industrialized plants whenever they run they produces a lot of ambiences which we considered to be as noise contamination, But this study is focused on such approaches which are principally concentrated on reaping and mining the energy from that noise and small movements which we are neglecting in our life on individual and cumulative or industrial level. In the quest of energy harvesting from past several decades multiple researches have been carried out and as energy is the prime concern to human race for its huge utilization, so many scientists have played role in bringing up the studies regarding such an important puzzle to boost and compensate the energy for individual as well as industrial sector (Joseph, 2005). The study scrutinizes that how reaping environmentally friendly energy in sensor systems vicissitudes the technique a product developer views energy administration and deliberates model devices. Then it recommends devices that syndicate energy reaping and data obtaining and then it sightsees innovative approaches for augmenting the power mined using piezoelectric materials. Last but not the least is to discover kinetic and thermal energy harvesting from human and living thing movements and activities. We habitually use energy reaping structures to alter and collect the environment's energy flows. A new vesture computation idea is bearing in mind that energy streams to be data flows. Contemporary piezoelectric energy harvesting research falls into two key areas: evolving ideal energy harvesting assemblies and highly effective electrical circuits to stockpile the generated charge or extant it to the load circuit. Our study focuses principally on the first area, in which the goalmouth is to create trivial, lightweight structures that twosome very well to automatic innervation and renovates the most serviceable electrical energy.

## **2.1. Types of Piezoelectric Crystals**

The study of piezoelectric energy harvesting has been gaining a lot of attention in recent years due to its pros such as high-power density, simple design, and scalability. As a result, there has been a significant increase in the number of studies on this topic, with more publications on piezoelectric energy harvesting than on electromagnetic or

electrostatic energy harvesting. This is largely due to the straightforward standards of piezoelectric energy transformation and the most utilized power-driven designs. A review of different types of piezoelectric energy harvesters has been presented, categorized into three groups: macro and mesoscale, MEMS scale, and nanoscale. The size of a piezoelectric energy harvester affects various elements such as weight, manufacture method, attainable power output, and prospective application areas. Therefore, grouping them constructed on size provides a useful way to compare different types of piezoelectric energy harvesters. The review of each group includes a synopsis, prospective application areas, and future guidelines. Additionally, the most significant trials in piezoelectric energy reaping and the researches addressing these trials are debated. Overall, piezoelectricity has become a key area of research in renewable and green energy, offering many benefits and uses that can provide humanity with an abundance of energy that will never run out (Hongtao & Wenjia, 2018).

## **2.2. Individual Analysis**

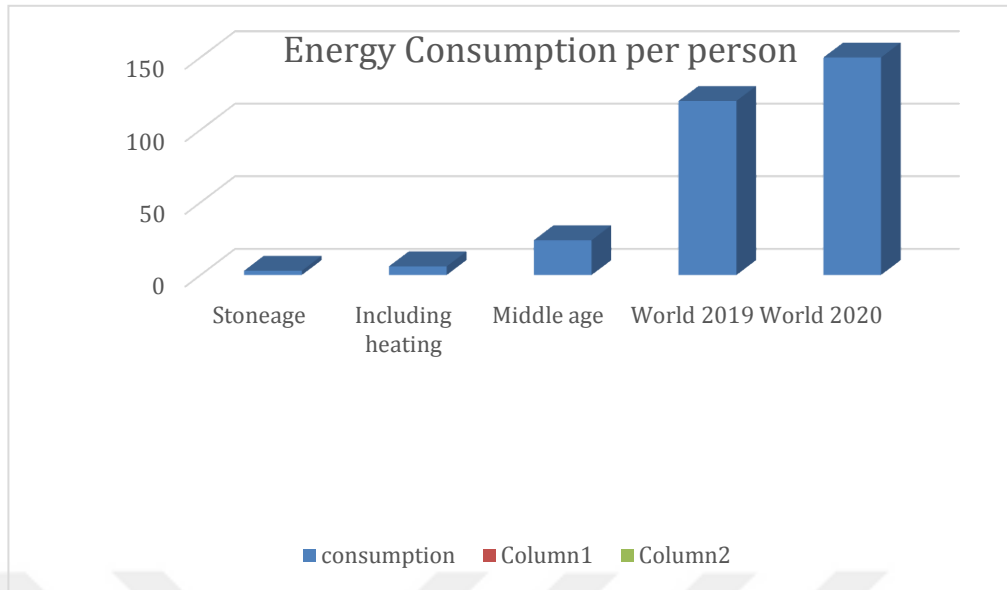
As technology advances and consumer habits shift, the worldwide need for energy is rising, leading to greater energy usage today and in the future. Adopting renewable energy sources to generate electricity is a worldwide solution as it is eco-friendly, sustainable, and less harmful, potentially enhancing the standard of living while producing and recycling energy. Some examples of commonly used renewable energy sources are solar, hydro, wind, and biomass. Inability to meet energy demand with domestic supply can result in high energy costs due to importing energy from other countries which leads to increase in cost of utilities and overall cost of living. Addressing the energy issue is vital for a greener and better future.

The piezoelectric effect is a characteristic of certain materials that converts mechanical pressure or force, whether compressional or tensile, into electricity; when a material is under pressure or strain, ions re-arrange, creating an electric displacement, which leads to the generation of an electric field as impulsive polarization in ferroelectric materials (Jettanasen et al., 2020). Over time, it has been researched for its potential use in biomedical applications, such as generating energy through muscle recreation, body effort, blood flow, lung and heart activity, and examining its

limitations and possibilities. Additionally, it has been studied for its use in automotive systems and has been found that fuel injectors consuming piezoelectric technology are additional precise than traditional fuel injectors.

The effects which we are devouring after the accomplishment of ambient energy reaping are praiseworthy and breath captivating. We can have a life-long energy being fabricated by a single human being till his/her last breath. This sometimes seems to be impracticable but these days it's very communal and the source has very less or trifling wear and tear (Erdiwansyah et al., 2019). Thus, the energy consumption issue in many parts around the globe is now being considered on national level and those nations already had started to counter it on individual level by creating smart apparels appliances which are self-sufficient or self-energy harvesting equipment.

For individual scale implementation, the data has been categorized as following for a single person on basis of daily energy consumed. This data includes all the electronic equipment that a person uses on a daily basis. Over time, people have been using more energy as technology has advanced. In the past, energy consumption was around 3 kWh per day per person and was primarily used for basic needs such as food. As heating became necessary for warmth, energy consumption boosted to 6 kWh per day in ancient times. During the Middle Ages, communities in Europe began to live more excessively, leading to an increase in energy consumption to 24 kWh per day. Nowadays, less than 6 kWh is used for basic needs such as food, with more than 12 kWh used for preparing and transporting food. This is the data which is mentioned in the below Figure 1, energy consumption graph for different ages until 2020 (Snurr & Freude, 2020).



**Figure 1.** Energy consumption graph

The 2019 statistics on energy feasting and populace display that the typical daily energy utilization of an individual in India is nevertheless just 19 kWh. However, China at 75 kWh is even now overhead the world average and will munch roughly the same volume of energy as industrial states in the next coming decades. In 2019, the world primary energy consumption was 13.9 billion ton. As of today, around the inhabitants of almost about 7.79 billion, we currently have a world average utilization of primary energy of 58 kWh pd/person.

Ambient energy has resolved this big issue by enabling every individual to be sufficient and capable of generating the energy on their own. The energy which is unlimited and can never run out. As we have given and come up with a solution that will provide a system which we can implement in shoe's sole and also alongside the breathing system of humans, the solution was designed because till the time human is living, he/she will manage to meet up his/her energy consumption requirements which we have mentioned above as 58kWh pd/person.

### 2.3. Industrial Analysis

The researchers investigated the potential of using piezoelectric technology in manufacturing processes and developed a method that improves the stability and efficiency of the system using piezoelectric patches. They also studied the ability of

piezoelectric materials to convert mechanical energy into electricity for use in roads and found that it is possible to harvest energy from roads. The research focused on techniques that can produce high power output and have a wide range of operation. The study also looked into the possibility of using piezoelectric energy reaping in building floors and proposed a method to maximize the energy produced from the energy reaping floor. The goal is to generate electricity from vibrations, and the proposed method can also generate energy from unwanted vibrations.

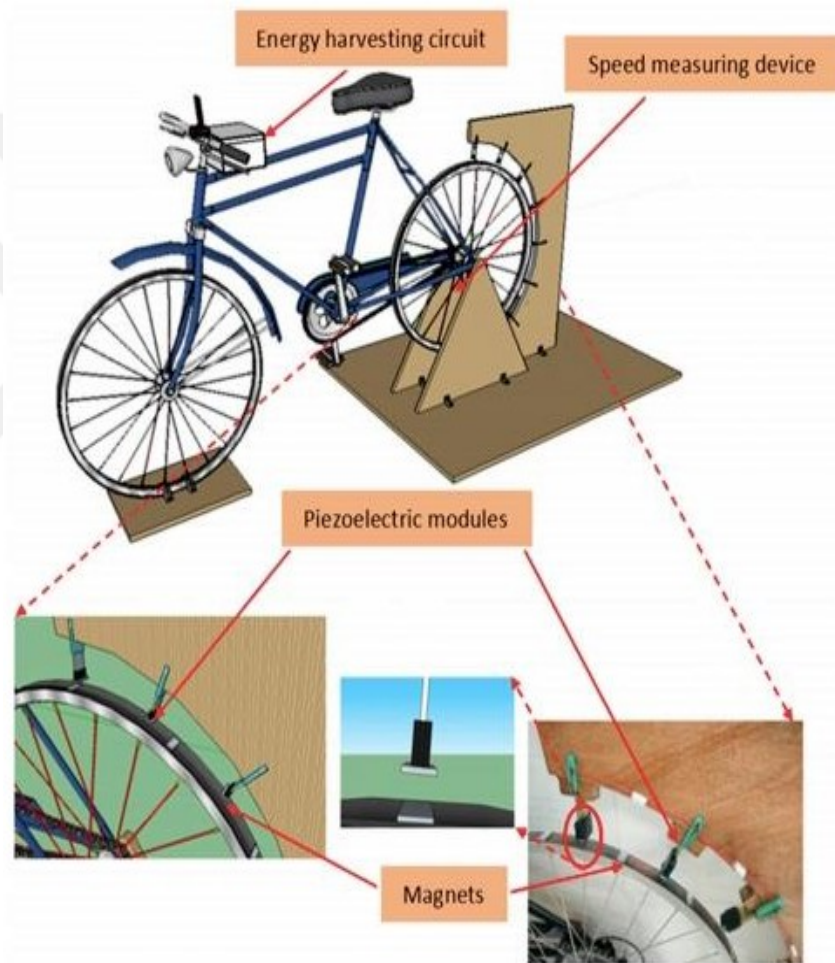
The topic of using alternative or clean energy sources to generate electricity is widely studied because it can be used for industrial purposes and can generate income if the energy is exported. It is also beneficial for the environment and can have a positive impact on tourism and health tourism. The research aims to investigate the effects of power electronics on the stability of the power grid and to develop a national energy strategy that prioritizes the use of renewable energy sources.

Industries are crucial for the development and prosperity of nations, but they consume large amounts of energy, which can be a problem for some developing countries. To address this issue, energy harvesting techniques are being used to create smart cities and self-powered houses, so that more energy can be used for industrial purposes. This study is focused on developing devices that are sensitive enough to detect vibrations from large machinery, allowing them to generate their own electricity from those vibrations and use it for their own purposes or to provide electricity for workers. This would decrease the use of other forms of electricity and help save power, ultimately contributing to the economy and preserving the environment on a global scale (Yang et al., 2018).

### 3. IMPLEMENTATION INSTANCES

#### 3.1. Individual Scale

The superlative individual research of this project has been carried away in many countries and laborites, but the one which we are focusing and mentioning in this study in based on many aspects including its affordability, availability and most importantly the amount of energy it is reaping in the end for an individual.



**Figure 2.** Energy harvesting bicycle.

In Figure 2, the energy harvesting bicycle is clearly indicating the model of a bicycle which is particularly designed for energy harvesting when any individual is riding a bicycle. In this prototype, basically piezoelectric modules have been used alongside the magnets to create the pulling effect in them whenever the wheel is

moved. So, these pulling effects will then create the vibrations in the piezo crystals. These vibrations are the cause for ultimate result to our electric power which then be controlled by our controller circuitry depending upon the usage for any device or storage purposes. The inclusive energy gathering flow chart is shown in Figure 3. A rectifier circuit transforms the electrical signal from AC to DC, with a capacitor organization engaged to diminish the ripple voltage (Snurr & Freude, 2020). A voltage regulator circuit is used to condense and sustain a persistent voltage that associates to two batteries; these 2 batteries grind as energy accumulators and supply power to load. Conclusively, a voltage converter upsurges or declines the voltage level to convene load requirements. Here in this model the piezo plates are generating energy on the basis of pressure being applied on them, which on the other hand will be converted in the electric energy. One important point here to keep in mind is that we are using a matt of only 7 ft length, for which we have to apply pressure in terms of routine walking only for 15 minutes and it will provide us with the energy supply for more than 1 hour. That will include one energy saver of 30W, mobile phone + laptop charging of power 450W and one fan of about the same power as 120W. Therefore, in general we are getting the number of 600W of energy for one hour in just 15 min of walking.

Let's make it achievable or even identical to the daily consumption need of a person according to our data given for 2020. If we assume that this matt or bicycle of ours is going to be installed in an area where the workout routine is 1 hour so the energy which we will get in complete one hour will be:

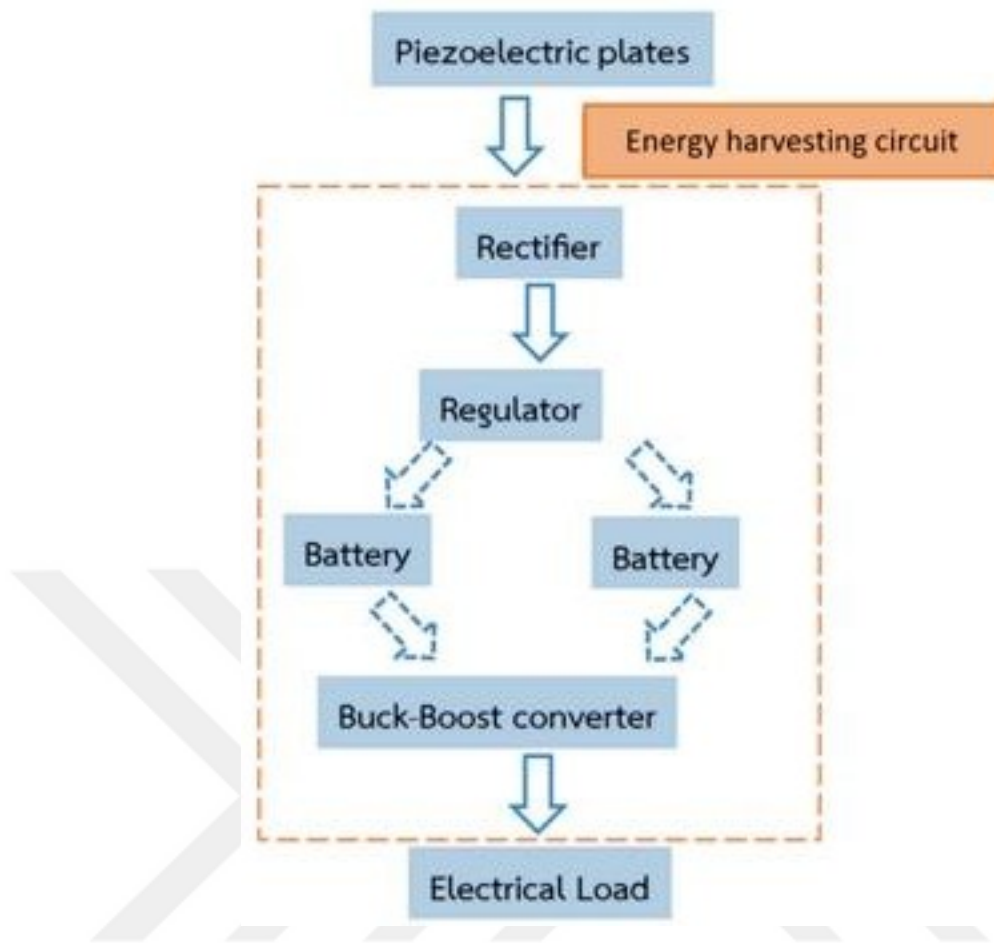
$$15 * 4 = 60 \text{ min}$$

$$\text{Energy in 15 min} = 600\text{W}$$

So, energy in 1 hour will be:

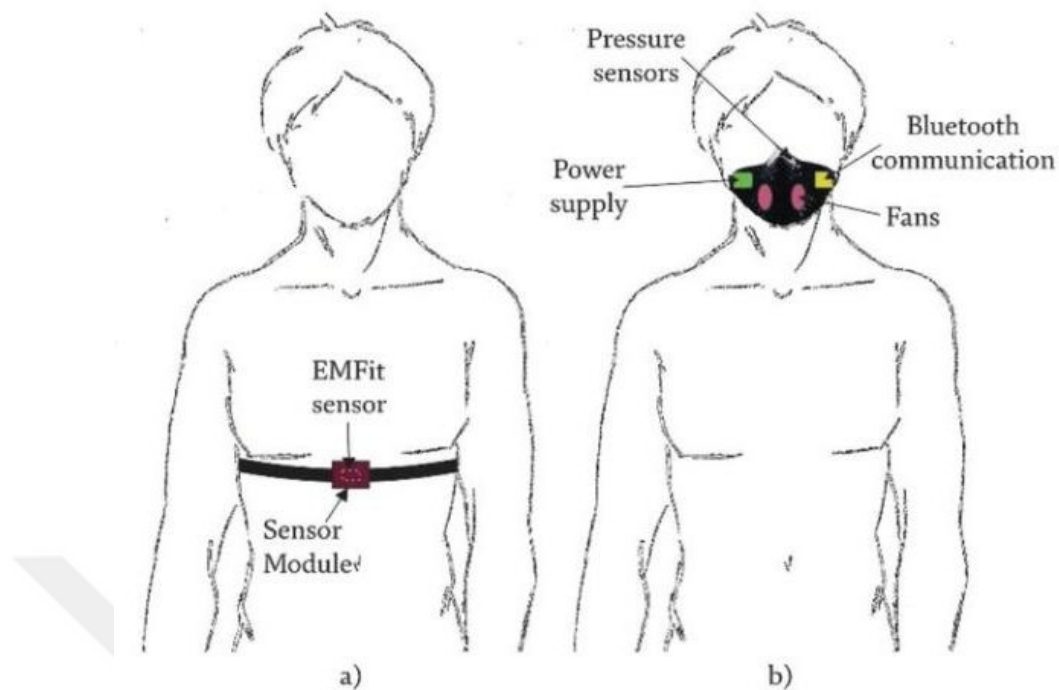
$$600 * 4 = 2400 \text{ W} = 2.4\text{kW}$$

As per stats, the energy consumption of a person is 58kWh per day. And we have generated the energy of around 2.4kW in one hour so, if we want to inculcate or energy need of the whole day, we can get  $2.4\text{KW} * 24 = 57.6\text{kW}$ , which is almost as equal to the amount of energy we required for a person in one day. It means that our model is providing a person to generate and utilize his own electricity.



**Figure 3.** Energy control flowchart

As proved previously by the daily consumption and generation, this model is designed to fulfill the daily energy demands of person. So, to make it simple and vivid our model will generate energy equivalent of 58kWh for an individual. This design is not portable so it can only provide the energy perks for that equipment which are meant to be used indoor, but we also have solutions and designs which are ambient breathing system (ABS) and ambient kinetic walking system (AKWS). These systems allow us to inculcate the energy on regular and continuous basis as you are moving and sitting or even sleeping. So, these two designs will provide you energy 24/7 for those devices which we do carry all the time. Now, coming towards our design which now a days is sort of compulsion to every person or its better to say that it's a part of everyone's wardrobe now, that is mask. We have taken this to another level that a mask which can give you continuous energy supply for your portable devices or even can store that energy when you are not using any portable device.



**Figure 4.** Portable individual harvester

In Figure 4, the mask and the chest vibration sensor modules have been mentioned which basically will be the ultimately game changer for the energy as focused on this study.

### **3.2. Industrial Scale**

The real-life implementation of these ambient energy harvesting methods has been first witnessed in Russia where they have been providing the electricity to a whole community or a village of more than 40 houses and providing them the electrical supply without any interruption. This electrical supply to that city or community is coming from the nearby road upon which they have made modifications and made it suitable to provide the electrical energy by merely the passage of traffic on routine and daily basis. This research aims to investigate the potential of using piezoelectric technology to harvest energy from the movement of vehicles on roads. It provides an overview of the principles of piezoelectricity, reviews relevant literature, and presents the results of developing and testing various prototypes for energy harvesting. The most promising prototype will be selected and incorporated into a series of modules,

known as HiSEC modules, placed in the wheel path of roads for energy harvesting (Papagiannakis et al., 2016).

Tables 1 and 2 are showing the development of the prototypes and their enhancement over the time depending upon their given outputs and results. You can witness yourself that studies in this filed have proven that prototype-I and prototype-IV have significant changes in their outputs. This is a clear symbol of our success.

**Table 1.** Traffic assumptions

<b>Traffic Property</b>	<b>Assumed Value</b>
Traffic speed (m/s)	22.2
Average annual daily traffic	30
Number of lanes	4
AADT/Direction	15,000
Number of trucks in traffic/day	2813
Number of cars in traffic/day	5625
Car tire load (kN)	6.667
Truck tire load (kN)	44.48

Now we are going to witness the changes in the first ever prototype and fourth version made for the big level generations which can be implemented on industrial scale to made changes in energy harvesting. Table 2 is showing the difference between prototype I and IV.

**Table 2.** Energy output for prototype I and IV

	<b>Prototype-I</b>	<b>Prototype-IV</b>
Number of elements/modules	25	1
Cross sectional area by piezo unit	0.000038	0.00155
Stress from car tyre	769.95	171.47
Stress from truck tyre	5136.84	1143.97
mWatts/car tyre pass	34.6	93.6
mWatts/truck tyre pass	1560	4098
Watt-hrs from car/year/module	1.58	4.3
Watt-hrs from truck/year/module	90.0	236.65
Total Watt-hrs per year/module	9.66	240.95

Vibration typically occurs when a system is stimulated by a repeating source. The sinusoidal wave is a basic waveform that represents repetitive motion. A mass attached to a spring can serve as an example of a vibrating system. If the mass is pulled down to the -20 mark and released, the spring will pull the mass up and past the zero point. The mass will reach the +20 mark, then begin to move downward again. When plotted against time, the oscillating movement of the mass creates a sinusoidal wave. The mass will resume to vacillate at an amplitude that will steadily diminish due to frictional losses. This sinusoidal wave is hampered because the energy put into the system by the preliminary pull on the mass was provisional. This fundamental vibrational model can be stretched to more complicated powered systems like a portable electric generator, which has a pulsation pattern that comprises of multiple sine waveforms combined. The main, recurring cause of pulsation for a transportable generator is the gas-fueled engine. In that engine, the piston is coupled to a crankshaft by a linking rod. The cycle of the crankshaft and the rhythmic up-and-down movement of the piston marked versus time creates a sinusoidal wave which, in this case, is undamped because the rotation of the engine continuously adds energy to the vibrational system. Below is a list of the equipment used in the testing. CPSC does not endorse the equipment and instrumentation used in the scheme, nor mentions that the equipment or

instrumentation used is the best or only for this application. The system is shown in Figure 5.

Generator rating 5250 Watts.

Gasoline engine 3600 RPM, 2250 Watts.

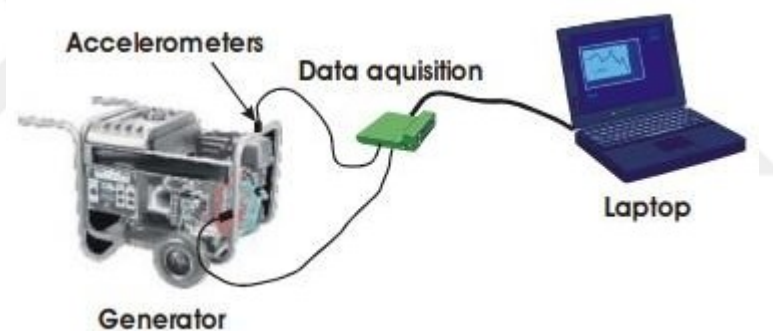
Gasoline engine 3600 RPM.

Accelerometer series 3030B Frequency response, 2 to 10,000 Hz  $\pm 5\%$  Range FS,  $\pm 500$  G.

Sensitivity @ 100 Hz 1G, RMS, 10.0  $\pm 5\%$  mV/G Linearity at FS,  $\pm 1\%$ .

Resonant frequency 30 kHz.

32-bit PC link Computer Laptop, 3GHz processor, 1GB RAM.



**Figure 5.** Generator vibrations

Five tests were steered with the 5250 Watt generator in succession. Data was engaged at origination, normal operation, and shut-down of the generator. Figure 6 shows a picture of the 5250-Watt generator.



**Figure 6.** 5250W generator

The accelerometers were placed at three different locations on the generator. Only two accelerometers were used at one time. The accelerometers were positioned on the generator's frame and/or on the control panel. Figure 7(a) illustrates the position of one of the accelerometers mounted horizontally on the generator's frame. Figure 7(b) shows the accelerometers mounted vertically on the generator's frame on the other side (Timm & Priest, 2005). The accelerometers were mounted at a 90-degree angle to the rotation of the engine shaft. Figure 7(c) depicts the third accelerometer being mounted on the control panel.



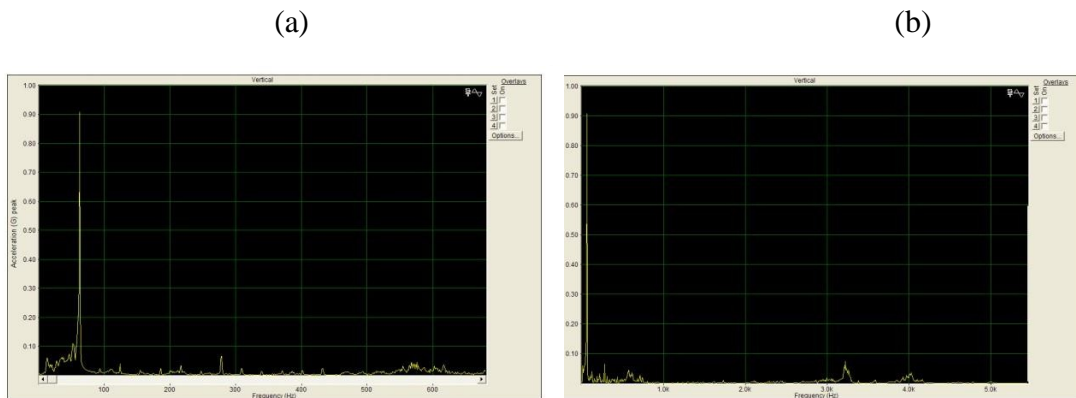
(a)

(b)

(c)

**Figure 7.** Accelerometer diagrams

These are the sinusoidal and spectral analysis of the vibrations observed by the accelerometers during a series of five tests we conducted. The results of tests 1 to 5 were all very similar. Figures 8(a) and 8(b) show the data in the vertical-axis peak-hold acceleration spectra from 0 to 5.5 kHz, and from 0 to 650 Hz, respectively. Most of the energy was at 61.57 Hz, with a peak of 0.91 G or 8.9 m/s<sup>2</sup>. It is understandable that the majority of the energy was around 60 Hz since the generator rotates at 3600 RPM or 60 rotations per second (RPS), which equates to 60 Hz.



**Figure 8.** Vibration graphs

Keeping in consideration all the data which we have taken for the vibrations in the industrial environment, we come to a conclusion that vibrations are really important and they exist on a level which won't go un-noticed so we put all together and devised an equipment which can harvest the energy from vibration on the continuous level. This harvesting can help us reap energy to be utilize in the industrial environment. The model which we have focused in this study is consisting of sensors which are sensitive and can harvest the energy on small vibrations. The amount of energy which is being harvest by using the sensor mentioned in Figure 9.



**Figure 9.** Piezoelectric crystal

These small sensors have amazing characteristics of producing the energy on every small vibration and can be magnified to a large scale by using them in parallel combination. So, industries can have a benefit of generating and producing their own energy while running. The magnitude of the energy being consumed by some of the industries in our area is mentioned below.

**Consumption data 1:**

**Knitss Tekstil Mağazacılık A.Ş.**

Energy consumed	year	/day
Kwh	2020	55.957
Kwh	2021	71.482

**Consumption data 2:**

**Novastore Hazır Giyim ve Mağazacılık A.Ş.**

Energy consumed	year	/day
Kwh	2020	39.233
Kwh	2021	29.057

Depending upon this, data we figured out that for a small industry like for textile and normal production store the amount of consumption is almost 7-8 times more than that of an individual person. Which means we need more sensitive equipment and more power to be generated.

So, the model which we presented is producing a voltage of 0.12V on a single vibration being created by a rain droplet or a vibration being created by any disturbance but this 0.12V is being created for only one push being given to that piezo crystal. So, our magnitude of vibrations from 5250W generator was around 60 Hz per second, if we do the mathematics it would reach near about  $60 \times 0.12 = 7.2V$  / second.

In a minute we can generate around 432V but this magnitude is quite less for a machinery being used in the industry and which has to be operated the whole day. So, this amount of energy is being controlled and collected to be used properly for the industry but it gives us a solution to harvest the energy which is a main liability on most of the industries which a purely running on electricity so if every machine can

produce its own energy from the vibrations, it is producing on normal routine than we can cope with major issue of world which the struggle against energy depreciation.



#### 4. QUANTITATIVE ANALYSIS

The widespread adoption of renewable energy (RE) is considered the ultimate, long-term solution to meet the world's growing energy needs. While some organizations, such as ExternE, have proposed ways to calculate the environmental external costs of energy projects, most governments, institutions, and energy market players only evaluate different projects and technologies based on their direct costs. Under this paradigm, the biggest obstacle to a full shift in the energy model is the relatively high direct cost of RE systems compared to traditional energy systems. The main differences between renewable and traditional energy project costs are due to the varying weight of operational expenses (OPEX) and capital expenses (CAPEX) in the final cost of energy. Traditional energy prices are primarily driven by operational expenses as they do not involve large capital investments and are mainly composed of the cost of fossil fuels (oil, gas, etc.). In such cases, capital expenditure has a relatively small impact on the final cost of energy, as large capacity factors and useful lives are achieved. Therefore, the financial analysis of traditional energy projects mainly focuses on estimating the future cost of fuels and energy selling prices, while the influence of CAPEX is less crucial and easier to estimate. The harvesters proposed in the study will have a significant impact on the two industries discussed in the previous section, which rely mainly on OPEX and are traditional energy consumption systems. By implementing the renewable energy system and comparing the cost and usage of those industries according to the consumption of renewable energy as per their data table, we will demonstrate the feasibility of the proposed solution.

The implementation is carried out at Knitss Tekstil Mağazacılık A.Ş., which has its headquarters in Merter, Istanbul, Turkey. Knitss is a Turkish knitwear brand, specialized in women's apparel. The company has stores in Istanbul, Ankara, and Bodrum. Moreover, its brands are sold at various global sales points located in the Americas, Europe, Middle East, North Africa, and Asia (<https://www.knitss.com/>).

The consumption analysis with costs per energy for Knitss for year 2021 was found out to be as, consumption per year in KWh 71.48/day. The unit price for the electricity in industrial sector is 0.96 Lira per KWh. As a result, the cost of the energy which is in the case of OPEX for Knitss is  $71.48 * 365 = 26,090.2 * 0.96 = 25,096.592$  Lira.

So, the calculation shows us that the operational expenditures for Knitss per year is almost 26,000 Liras, which for an enterprise like Knitss is expensive on the other hand the capital expenditure model which in our case is renewable energy harvesting model. This will cost only the installation of piezo crystals for Knitss and according to estimates made by the prices of those crystals being used and installation cost of the system is concerned by the model which has been built in past.

Cost of 20 Pcs = 7.5 \$

1 unit = 30 pcs dimensions (1.5 ft<sup>2</sup>)

Cost of 1 unit = 10.75 \$

So, the cost of installation for 1 room renewable energy backup and harvesting just merely by walking of vibrations will be completed by installing only 9 units in 1 room which makes up the calculation to:

$9 * 10.75 = 96.75$  \$

As a result, taking into consideration the number of rooms for Knitss as per our research, it was 15 rooms and some supervisor and management rooms so in total 20 rooms. So, the installation cost or CAPEX for Knitss will be equal to this number:

$20 * 96.75$  \$ = 1935 \$ (34,329.80 Lira)

This is the cost of capital expenditure and installation of the renewable energy harvesting system just to make it clear that this is the first time only investment required for any enterprise. So, from the day of installment to further usage the cost will be zero and in a time of 1 year and 3 months the enterprise of a size like Knitss will start making profit.

Now coming to the wear and tear of the system and pros and cons of what we have suggested and tried to replace. The conventional system which everyone is using just because no one know the pros of the RE or we are afraid to take the initiative or risk of using it or installing it. Conventional system looks easy because it does not ask you for capital investment for electricity consumption mostly around the world this electricity consumption and production is mainly handle by the government bodies or authorities, for which they ask us for some subscription price on opening a connection and then per month cost of using it which we have already discussed in case of our

pre-existing enterprise Knitss. Keeping in view the cost analysis of OPEX to our proposed CAPEX system is indeed resounding. The capital expenditure model for Knitss is resounding and appealing from many views. Why? Answer to this is here that the operational cost for only electricity consumptions for the year for this small enterprise is 26 K Lira which will increase as per the tariff for electricity will increase every year which means that the OPEX will keep on adding every year which none of the enterprise wants today keeping in mind the ongoing inflation, but contrary to this the renewable energy installation will cost 35 K Lira which obviously is more than the total year running cost of its electricity consumption but the pros is even more money-spinning, which means no surplus amount has to be paid after the installation has been done. Now, profit and loss point of view for the enterprise for using the CAPEX systems is decoded in the way that we only take in consideration the electricity consumptions cost to compare and evaluate, o for this case the calculations are as under

OPEX or conventional system: 1 year

Consumption/ Expenses = 26 K Lira

CAPEX or renewable energy systems: 1 year

Consumption/ Expenses = 35 K Lira

The time to reach it break-even point to start earning profit will be calculated and discussed by using the Break-Even Price of Energy of both systems.

Due to the elevated risk involved with renewable energy sources (REs), it is crucial to assess the economic feasibility of each plan by taking into account maximum variables involved in the industrial and fiscal viability. This requirement, coupled with often limited financial resources, necessitates the need for a reliable assessment tool to aid in the conclusion creating process of which plan is more appealing to capitalize in, in order to capitalize on long-term productivity. This study introduces the Break-Even Price of Energy as a fiscal marker that can be utilized to compare not only various tools among themselves but also ventures based on the same equipment with different structures, designs, and dimensions. This statistic allows for evaluating different funding arrangements, the impact of various legitimate structures with regard to excise methods, depreciation schemes, etc.

#### **4.1. Justification**

A frequently used monetary marker for evaluating and equating renewable energy ventures is the Levelized Cost of Energy (LCOE), may be called as Levelized Energy Cost (LEC). This expense of energy is basically determined by splitting all expenses, such as capital and operational expenditures, lowered to a current value by the aggregate electricity yield, also reduced to a current source. The particulars of this computation are widely clarified in narrative. Even if the LCOE has been extensively utilized for equating machineries and developments on an expense basis from a comprehensive standpoint, it has restrictions that bring about inappropriate for opting between jointly special substitutes and neither for assessing plan-specific conclusions. Additionally, Levelized cost of energy ought not to be utilized as a computation of feed-in prices. This study does not aim to delve into the applicable relevance of the LCOE or beyond to analyze its shortcomings, but to suggest a flattering indicator that is able to make a contrast between regular energy usage and renewable energy usage. With the modernization of most energy flea market in the world, energy production projects are developing progressively more revenue oriented. In this manner, a monetary marker for assessing different technologies should be based on the profits generated by selling the energy rather than the cost of it.

#### **4.2. The Break-Even Price of Energy**

From an inventor's perspective, the most important factor to consider is the effectiveness of a scheme, which is determined by the cost at which energy is offered (Garcia-Barberena et al., 2014). This price must be higher than the cost of manufacturing the energy. The indicator that is recommended to measure this is called the Break-Even Price of Energy. It is the price at which power must be offered over a certain point in order for the cash flow to be balanced and the Net Present Value (NPV) to be equal to null. If the selling price is above the BEPE, there will be a positive NPV, but if the price is below the BEPE, the NPV will be negative. The (BEPE) computation is parallel to the Internal Rate of Return computation, where goal is to find the expense of investment that creates the NPV zero with a permanent retail price. To calculate the BEPE, the cost of equity or predicted internal rate of return for the project must be specified as input. In simpler terms, it can be stated as in Equation (1).

$$BEPE(TL/KWh) / NPV = \sum R(BEPE)_i / (1+d)^i = 0 \quad (1)$$

where:

*BEPE* is the Break-Even Price of Energy.

*NPV* is the net present value.

In this calculation, "*N*" represents the number of years for taking out this computation, which is typically the same as the amount of the anticipated beneficial life of the enterprise and the manufacture phase of the venture. "*R<sub>i</sub>*" is the money flow in the year "*i*" where "*i*" ranges from 1 to *N*. "*d*" is the discount rate, which represents the current value of potential cash streams that depend on the debt gain and the anticipated investment effectiveness (anticipated internal rate of return). The discount rate is usually computed as the Weighted Average Cost of Capital, taking into account costs of both liability and equity. The cash stream in year "*n*" is determined based on the fiscal factors characterized in Equation (2).

$$R(BEPE)_i = O_i(BEPE) - D_i - T_i - Q_i \quad (2)$$

*O<sub>i</sub>* signifies the working consequences in the year *i*, this infers the net gain gotten from the energy trades once reduced financial costs and process expenditures. This power transactions gain is premeditated utilizing the (BEPE) as the vitality cost. In this scheming anticipated price increases is not affected.

*D<sub>i</sub>* is the yearly devaluation of principal assets in the year, which we are keeping as 0 in this case.

*T<sub>i</sub>* is the taxes cost in the year *i*.

*Q<sub>i</sub>* is the investment cost in the year *i*.

This tenure will be merely taken in account throughout the preliminary financing phase.

In Table 3 below, the conversion and BEPE of the Knitss has been discussed. This is just the prototype of a small enterprise as to take in account the example of how industries will make difference while using renewable energy.

**Table 3.** Break-even price of energy calculations

Knitss Tekstil Mağazacılık A.Ş. wants to determine the break-even point, and aims to generate a profit of \$40,000. The total fixed cost of a consumption is \$26,000, variable expenses per month is \$2200, sales per month is \$6000.	
Desired Profit (\$)	40,000
Total Fixed Cost/Expenditure (\$)	26,000
Energy Consumption/Month (\$)	2200
Sales/Month (\$)	6000
Break-Even Point in Units	6.84
Break-Even Point in Dollars	41,052.63
Number of Months to Produce the Desired Profit = Desired profit in Dollars / (Sales per Month – Variable Consumption per Month) + Break-Even Point of Unit	
<b>No. of Months to Produce the Desired Profit</b>	<b>17.37</b>

The above table has done the break-even calculation in such a manner which is being discussed as under in proper detail to be carried further if necessary.

Break-Even Point in Units = Fixed Cost / (Sales Price per Unit – Variable Cost per Unit)

Then, for finding the value in dollars the points will then be converted into the desired currency as follows:

Break-Even Point in Dollars = Sales Price per Unit \* Break-Even Point in Units

Rest of the formulation is about finding the total amount of months to reach the preferred revenue which is:

Number of Months to Produce the Desired Profit = Desired Profit in Dollars / (Sales Price per Month – Variable Cost per Month) + Break-Even Point of Unit

Now is the time to discuss whether these result and analysis take us to the whereabouts of the profitability. As per the calculations and analysis being carried out on Knitss, we found out that the Break-Even Price of Energy would be recovered in just 17 months for reaching a profit amount of \$40,000 which is commendable in terms of achieving the target in such early tenure. The points in this table are focusing mainly on the cost analysis which separates our model from conventional way of energy consumption model, so this break-even analysis provides us the fundamentals which says that our model can achieve the break-even prices which no recurring costs in just 17 months after its establishment and then later on it will be your complete profitable investment coming. The one factor which make this profit to be achievable in case of CAPEX is that the investment cost is being expended only at the beginning and there is no other recurring cost being involved. Now, discussions on the OPEX model which in case if Knitss is having the energy consumptions cost of around 26,000 Lira. In this model, the recurring cost of energy is more than that of the scenario which has been discussed above which makes it difficult to achieve. Reasons for what it's not possible to achieve in same tenure is that its variable cost will be increased which has a huge impact on the BEPE in case of the operational expenditure model.

## 5. CONCLUSION AND RECOMMENDATIONS

Obviously, the consequences will be worth mentioning that merely just by walking of an individual would be able to produce his/her own energy for his use which then can certainly reduce the energy which we are utilizing from governmental sources. So, this can benefit on a global level to retain and maintain the reservoirs of fossil fuel and other energy resources. From the above-mentioned implementations and examples, it is very obvious and vivid that in coming near future every nation is now focusing its major part of the yearly budget to invest in the development of energy harvesting for better reaping. On the industrial level as described in the study that energy is being consumed per day on a large scale for which we present a solution to implement and install the piezoelectric crystal on every machine which have some vibrations so we can take advantage of all those vibrations to harvest energy. Hence, this study recommends the best ways to bring in the eco-friendly energy sources for long and indefinite period.

This work presents a financial indicator for RE projects based on the Break-Even Price of Energy, which is characterized as the energy retail cost at which the venture turns out to be lucrative. Therefore, this indicator is primarily intended for capital expenditure-focused ventures and is typically proposed for renewable energy ventures; The Break-Even Price of Energy is a method for determining the profitability of an energy project by calculating the retailing price that brands the net present value of the venture equal to null, based on an obligatory rate of profit for the equity. However, this technique can also be applied to conventional energy or operational expenditure projects. The more detailed and comprehensive the financial model is for calculating the venture money streams, the accurate the BEPE will be. The BEPE is useful because it overpowers specific constraints of frequently used markers when analyzing various socioeconomic and legitimate situations.

Furthermore, since most renewable energy projects are profit-driven and motivated by the rate of return for a specific shareholder, it's more suitable to use an economic indicator that accounts for this when analyzing them. It's important to keep in mind that, like any other financial indicator, the BEPE does not account for changes in

policies or technology. But this indicator can be used to conduct stochastic studies to account for this limitation to some extent.



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