# Energy harvesting schemes for internet of things: a review

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**ABSTRACT**

As the internet of things (IoT) grows quickly, more people are interested in making wireless, low-power sensors. IoT systems currently use wireless sensors to collect reliable and accurate data in areas like smart buildings, environmental monitoring, and healthcare. Wireless sensors have typically been driven by batteries, which, although allowing for low total system costs, can have a significant impact on the whole network's lifetime and performance. The solution to this problem is energy harvesting (EH) from the environment. An EH is a technique for converting energy from an environmental source, such as heat, light, motion, or wind, into electric power. This paper describes many types of EH systems as well as some technological issues that must be solved before IoT energy harvesting solutions can be widely used.



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## 1. INTRODUCTION

Due to increasing population and economic growth, electricity consumption has increased significantly in recent years, resulting in a scarcity of fossil fuels and an increase in environmental harm. Due to these conditions, there needs to be a lot of research into sustainable energy harvesting and conversion devices like piezoelectric (PZT) harvesters for mechanical power, solar cells for sunlight, thermoelectric generators (TEG) for gradient heat sources, and so on. Nowadays, our continued reliance on nonrenewable energy sources, along with the need for power, has compelled some to investigate alternate energy sources or transform ambient electricity in our surroundings into useful form. So, the goal of current studies of electricity is to promote clean and renewable energy in ways that are good for the environment. This is how the idea of "energy harvesting" came to be. Energy harvesting is the technique of extracting energy from external sustainable energy sources such as solar rays, electromagnetic (EM) waves, and so on and efficiently storing it for use in different application systems such as wireless sensor networks (WSNs), wearable technology, and so on. The notion of energy harvesting leads to substantial reductions in recurring costs since, once the equipment is in place, it may create power at a zero cost from freely accessible renewable sources in the ambient environment. Researchers have become increasingly interested in WSNs with energy harvesting in recent years because of their widespread deployment and ubiquity in emerging areas such as the internet of things (IoT), smart buildings, cyber-physical systems (CPS), and several others. Advertising will grow quickly in the near future because it will be used everywhere and by everyone. As things (items) have grown more affordable, compact, and sophisticated, an increasing number of them have been linked to the Internet. These gadgets have been linked to the Internet, opening the door for the expansion of the IoT. Most peripheral sensors and gadgets of the IoT are powered by low-capacity, short-lived batteries that must be changed every few years. However, the functioning of WSNs has been related to a number of critical challenges and their unique characteristics. WSNs face a significant energy restriction, making it difficult to conserve their batteries before they empty. In a WSN, communication is often erratic because of the large number of static sensor nodes that have low power reserves. To solve this important problem, researchers have shown how to design and use energy-harvesting devices that work well and efficiently in WSN topologies. This paradigm enables scientists to offer dependable and limitless energy to WSNs. As a result, energy harvesting in WSNs is the perfect way to generate electricity from a network's ambient environment and provide a continuous power supply [1]. The review broadly categorizes energy harvesting strategies and reveals several powerful approaches researched by diverse researchers, resulting in significant discussion. The main goal of this study is to get researchers to pay attention to the wide range of energy harvesting techniques for the new field of IoT.

## 2. TYPES OF ENERGY SOURCES

### 2.1. Light energy

Sunlight is often regarded as a plentiful form of renewable energy capable of powering equipment [2]. Photovoltaic (PV) panels, which are made up of many arranged photovoltaic panels, employ the photovoltaic effect to turn sunlight into electricity. A single solar cell consists of three main parts, with metal composing the bottom and top layers. Together with a p-n junction layer that turns direct sunlight into energy, the changed current is sent to the load [3], [4]. Electrical energy may be generated either outdoors or indoors. Indoor solar energy sources are frequently created in artificial ways. The ambient solar sources of energy in the interior environment, which are often artificially simulated, are quite feeble. As a result, the amount of energy harvested indoors is affected by factors such as light intensity and spectrum, incidence angle, light source size and sensitivity, temperature, and so on. The lighting efficiency in an outdoor situation exposed to direct solar radiation is often quite high [5].

### 2.2. Thermoelectric energy

Thermal energy, often known as heat energy, is present in both indoor and outdoor situations. Human body heat , electrical devices (engine heat), or temperature gradients may all produce it. Heat energy can come in many forms, such as engine exhaust heat, heat from the sun, heat from internal resistance, and temperature gradient. Over time, thermal availability changes. We may convert variations in temperature or heat produced by several sources into electricity to provide IoT networks with a steady supply [6], [7].

### 2.3. Mechanical energy

Mechanical energy gathered from ambient vibrations requires a significant amount of work to convert to electricity using one of the following transformation concepts: electrostatic, electromagnetic, or piezoelectric, allowing identification of a renewable and sustainable EH [1]. The electrostatic approach is based on the conservative Coulomb force, which states that as the distance between two charges in a capacitor change, electrical energy is created, resulting in current production in a circuit [8]. The electromagnetic harvester is another type of mechanical harvester. Faraday's law of electromagnetic induction, which says that "whenever a conductor moves inside a magnetic field, there will be an induced current in it," is the fundamental premise of the construction of an electromagnetic energy harvester [9]. The piezoelectric energy generation method is based on the fact that when a material is put under mechanical stress, it can create an electric field. About 200 different piezoelectric materials are used in energy harvesting devices. These materials fall into four main groups: polymers (polyvinylidene fluoride (PVDF)), single crystals (Rochelle salt), ceramics (lead-zirconate-titanate (PZT)), and polymer composites or nanocomposites (polyimides-PZT) [10], [11].

### 2.4. Radio-frequency energy

Radio frequency (RF) transmission from hundreds of thousands of radio transmitters, such as mobile base stations, cellular phones, and television transmitting terminals, is prevalent all over the world. The ability to capture RF energy from ambient or dedicated sources simplifies mobile device charging and has a positive impact on product design, uptake, and dependability. Both dedicated RF energy harvesting and ambient RF energy gathering are conducted. Dedicated energy harvesting, in particular, refers to a harvesting strategy in which RF sources are dedicated to delivering energy to a specific IoT sensor [12]. The fundamental advantage of such sources is that they are available 24 hours a day, seven days a week, both indoors and outdoors. The rate of technical advancement is at an all-time high, and the number of wirelessly linked devices, particularly cellular communication systems, is expanding on a daily basis. As a result, the availability of energy for harvesting will increase in the near future [13], [14].

### 2.5. Chemical energy

Chemical energy may be produced readily by chemical reactions, biological activity, or changes to chemical substances. The human body is a great example of the way food is turned into energy by the body's biological system. Battery creation is an uncommon instance of converting a chemical method into electricity. Biological waste and corrosion are the most common and easily available sources of chemical energy, and we may use them to power IoT sensor nodes [6].

## 3. ENERGY HARVESTING TECHNIQUES

### 3.1. Light energy harvester

The photoelectric effect, often known as photovoltaics, is the most popular way of gathering light energy. Solar panels are another name for PV panels. A typical panel has two layers of semiconducting material, like silicon, with P-type and N-type components added to each layer. Solar energy is exposed to the interaction with the N-type layer. When light hits the material, photons are taken in. This lets electrons flow into the PN-junction. This plugs the P-type material's gaps. Some of the electrons that are not used are returned to the N layer. As a result, a current is generated around the PV panel [6], [15]. PV panels are categorized into three types based on their construction materials: amorphous silicon, polycrystalline, and monocrystalline, or thin-film cells [16], [17]. A lot of factors influence the energy generated by PV panels, including ambient temperature, radiation, and the solar panel's set point management with its voltage-current operation. Lately, a lot has been done by researchers to reach the highest energy generation of solar panels [18], [19]. A solar energy harvesting system's essential components are a PV cell, a rechargeable battery, a DC-DC converter, and maximum power point tracking (MPPT) management. The PV panel harvests ambient solar light energy and converts it to electrical energy. Before sending the collected voltage to the battery, the DC-DC Buck converter cuts down on and controls how much voltage is sent. The MPPT controller changes the duty cycle of the MOSFET in the DC-DC Buck converter based on how much current and voltage are coming from the PV panel. Lastly, the wireless sensor node is powered by the battery voltage. The WSN provides sensing, processing, and communicating with other nodes that have similar capabilities [20], [21]. The performance of PV systems is tied to geographical differences, both in cities and in isolated places. The amount of solar radiation a solar cell gets is directly affected by where it is in the world, how fast the air is moving, how much dust and humidity are in the air, and how much pollution is in the air. Each of these elements contributes to low production and fluctuating performance in PV [22].

### 3.2. Thermal energy harvester

Thermal energy may be transformed into electricity using either TEGs, which operate on the Seebeck effect, or pyroelectric generators (PEGs), which work on the reorientation of dipoles caused by temperature changes [23]. The Seebeck effect, in association with the thermoelectric effect, can be utilized to harvest energy from thermal sources. The TEG property of a thermoelectric material, the Seebeck effect, can be used to turn the difference in temperature between the human body and the surroundings into output power [24]-[28]. To create a TEG, a p-type material and an n-type material are connected in series. Thermoelectric materials transfer heat by moving electrons from the warmer to the colder material when their temperatures vary. A closed circuit is made as electric current flows as a result of the operation [29]-[31]. The pyroelectric method is another typical thermal energy-harvesting approach. This method employs a particular crystalline substance that creates potential when subjected to temperature variations in its surroundings. Temperature differences induce atoms to relocate and modify the polarization of the substance. This generates voltage energy across the crystal [6], [32]. The thermal energy harvester consists TEG, DC-DC converter, MPPT, rechargeable battery, and sensor node [12].

### 3.3. Mechanical energy harvester

Many methods that available to convert mechanical energy to an electrical energy harvester including electrostatic, piezoelectric, and electromagnetic methods. Mechanical vibrations are used to move charging capacitor plates in a changing structure versus electrostatic forces between electrodes isolated by vacuum, air, or a dielectric material in electrostatic energy harvesters. ESEHs require a battery-supplied DC voltage (bias voltage) to charge the capacitor plates in the opposite direction. ESEHs have a wider spectrum of lower frequencies, the capacity to create inexpensive devices, a higher output voltage, and a comparablely better power density of output [17].

Another form of mechanical harvester that is often employed is the electromagnetic harvester. Faraday's law of induction governs the harvesting process in the electromagnetic approach. The displacement of a magnet around a coil, like Faraday's law, aids in the creation of current at the coil's termination. A permanent magnet moves within a harvester coil to generate current. Electromagnetic harvesters' efficacy may be altered by carefully adjusting the magnet bar composition, coil thickness, and number of coil winds [6].

Piezoelectric energy harvesting is a technique for converting mechanical energy into useful electricity [33]. The technology of piezoelectric energy harvesting relies on the ability of the material to generate an output voltage when subjected to mechanical stress [11]. Because the created electrical energy is in the form of alternative current (AC), it must be converted to the direct current (DC) using a rectifier [34].

### 3.4. Radio frequency energy harvester

RF energy harvesting is a way to get power for low-power devices and sensors on the IoT. More low-power gadgets develop as technology nodes decrease, making RF energy harvesting even more tempting. This is because it has enticing benefits like low cost and easy maintenance, which are especially important when IoT devices are used in hostile environments that make regular maintenance hard [35]. There are electromagnetic waves all around us. Radio stations, mobile phones, and other communication technologies are used to create them. In the twentieth century, the notion of extracting RF from the environment and transforming it to DC was created. A rectifying antenna, also known as a rectenna, can be used to transform RF waves into usable energy for powering equipment. Several rectennas are triple-band or dual-band to increase power gathering [36]–[39].

### 3.5. Chemical energy harvester

For a long time, several chemical energy harvesters have been in use. A microbial fuel cell (MFC) is a novel method for generating renewable energy. An MFC uses native bacteria as biocatalysts and can turn any biodegradable material into energy. This makes the process a good choice for recycling waste in a sustainable way or making power on its own. The MFC technique has received a great deal of attention in recent years as a novel technology that offers a means of producing ecologically friendly energy by disposing of waste and generating power. Active microorganisms are used by MFCs to electrochemically generate electricity from their environment [40], [41].

A proton exchange membrane (PEM) physically separates an MFC's anode and cathode chambers. In the MFC, bacteria act as catalysts to break down organic materials into protons and electrons. The electrons are then moved to the anode through the PEM, while the protons are moved to the cathode. If an external circuit is connected to the anode and cathode, electrons made by the anode will flow through this circuit to the cathode. Electrons and protons interact in the cathode chamber as oxygen is converted to water in parallel [42], [43]. Table 1 summarizes the technology utilized to gather energy, the advantages and drawbacks of various methods, and the achieved power density ranges.

Table 1. Energy harvesting analysis

| Energy harvester | Techniques | Power density | Advantages | drawbacks | References |
|---|---|---|---|---|---|
| Light energy harvester | PV Panel | 100 mW/cm$^2$ (outdoor) | High power density, low production costs. | Nights are not available. Materials are costly. | [17], [44], [45], [46] |
| | PV Cell | 100 µW/cm$^2$ (indoor) | It is abundant indoors and is simple to implement. | Power density is low. Materials are expensive. | [8], [44], [47], [46] |
| Thermal energy harvester | Thermoelectric | 60 µW/cm$^2$ | Widely available | output density is low. | [4], [8] |
| RF harvester | Rectennas | 1-10 µW/cm$^2$ | Available Implantable. | dependent on distance. | [44], [48] |
| Mechanical energy harvester | Piezoelectric | 4 - 250 µW/cm$^3$ | Power density is high. | Output that is very varied | [17] |
| | Electromagnetic | 300 - 800 µW/cm$^3$ | no smart material | The size is relatively large. | [17], [49] |
| | Electrostatic | 50–100 µW/cm$^3$ | High-output voltage | Bias voltage is required | [17] |
| Chemical energy harvester | microbial fuel cell (MFC) | Combining four MFCs yields 1.5 mW. | low-maintenance voltage sources. | The output power of a single MFC unit is extremely low. | [6] |

## 4. TECHNICAL CHALLENGES

The internet of things (IoT) is a technological revolution. Battery-powered IoT presents difficulties in managing the energy budget. Energy harvesting in an IoT system presents a number of issues. This section addresses critical design challenges for an IoT-harvesting system. They are as follows:

### 4.1. Modeling of harvested energy

Keeping the ratio of generated to used electricity stable is crucial. To do this, IoT devices need to make a good energy profile and change how they work based on how much energy they get. With time, the quantity of energy gathered fluctuates in a non-deterministic way. Recent proposals include improving power prediction models to get more accurate findings and making power management choices to reduce energy loss. Also, the power supply must be able to provide sufficient power for transmission, reception, data processing, and sleep [17].

### 4.2. Energy storage

Two energy storage mechanisms (battery and capacitor) are used in sensor systems to store energy. For a long-lasting network, selecting the correct storage device is crucial. Because of their limitations, batteries and super capacitors can't be used in many IoT situations. When it comes to sensor networks, lead-acid batteries are by far the most popular option. The energy supply is quickly depleted, which is a major drawback. Therefore, it is not suitable for IoT networks on a broad scale. Although it costs less, a NiCd battery has a poor energy density. On the other hand, NiMH and Li-ion batteries have high power densities but low discharge rates. Super capacitors are one of the best solutions for IoT networks due to their many benefits. A super capacitor, on the other hand, is a newer technology [6].

### 4.3. Energy harvesting from multiple sources

Obtaining energy from different sources is one of the trickiest issues, so better energy management systems must be put in place. To address the energy requirements of sensor nodes, a general plug-and-play energy harvesting capability capable of gathering energy from a variety of sources is required. Researchers should also focus on making complex algorithms that can choose energy input sources based on their availability [50].

### 4.4. Size and cost efficiency

When it comes to wearables and implantable IoT devices, the weight and size of a device are very important. However, the energy that is produced by these gadgets is insufficient for them to carry out their main purpose (i.e., powering the device and the attached sensors and data transmission). Small harvesting technologies (nano and micro) must be made with low production costs in mind in order to power IoT devices and help with other things, like keeping an eye on a patient's health or helping tissues heal [17].

### 4.5. Design of a protocol

To deal with the problem of nodes using too much power, IoT systems need to use a strategy that saves energy. In addition to energy-aware and energy-saving protocols, harvesting systems also need a supply-aware protocol. A supply-aware protocol needs to be able to deal with how electricity is collected, which can change a lot, as well as long power outages [6].

## 5. CONCLUSION

An Several energy sources in the surroundings might be researched in order to provide renewable energy to support the potential IoT and WSN applications. This paper discusses the most frequent energy sources that can be gathered. Because ambient energy may be found nearly anyplace there is vibration, sunshine, heat, radio frequency, and a variety of other natural sources, energy can be gathered immediately in the neighborhood of the application. This will guarantee that the benefits of EH systems are maximized, such as cheap maintenance costs and reliability. Energy harvesting systems have been considered a game changer in the field of green communications. Because of the pervasive interconnectedness of IoT devices, energy harvesting capabilities promote their application as long-lasting energy sources. This study highlights and reviews phenomena related to facts and occurs with concepts leading to important ways of energy collection.

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