# Optimizing RCA and Related Products Production process using Renewable Energy

*Santhosh* Paramasivam[1*], *Arnas* Majumder[2], *Amit* Kumar[1], *Arumugaprabu* Veerasimman[3], *Flavio* Stochino[2†], *Gianluca* Gatto[1‡]

[1]Department of Electrical and Electronic Engineering, University of Cagliari, Cagliari, Italy
[2]Department of Civil Environmental Engineering and Architecture, University of Cagliari, Cagliari, Italy
[3] Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

**Abstract.** The change in climate and the increased frequency of unexpected natural disasters (like earthquakes, landslides, floods, and such) has induced obligatory interest in the construction industry focusing on sustainable practices, particularly in producing recycled concrete aggregate (RCA) and related products to reduce environmental impact. This study highlights the significance of integrating renewable energy sources and advanced power electronics to enhance the RCA production process. Using renewable energy systems helps minimize the carbon footprint of crushing, sorting, and processing concrete waste. Power electronics are critical in enhancing energy efficiency, enabling precise machinery control, and ensuring seamless integration of intermittent renewable energy into the production workflow. The study evaluates this approach's technical and economic feasibility through case studies, emphasizing potential energy savings, reduced operational costs, and enhanced sustainability metrics. The incorporation of renewable energy systems with power-electronic technologies would be a effective and efficient choice for transforming the traditional RCA manufacturing process into energy-efficient. The innovative adoption of vibration-based energy harvesting making use of mechanical waste (vibration) into useful energy elevates the RCA Process and products a green and sustainable. In conclusion, this study and proposal enhances the understanding of sustainable construction materials and offers insights for researchers and industry stakeholders aiming to utilize eco-friendly technologies.

## 1 Introduction

The construction of buildings and other infrastructure relies on natural aggregates for their raw (building) materials across the globe. Advancement across various fields demands for

* Santhosh Paramasivam: santhosh.paramasivam@unica.it
† Flavio Stochino: flavio.stochino@unica.it
‡ Gianluca Gatto: gianluca.gatto@unica.it

the infrastructural expansion / enhancing the existing infrastructure to accommodate the change in progress. This results in increased construction, demolition, and reconstruction of buildings and other infrastructure. The other key parameters that influence the cause are the increase in urbanization and the need for developing sustainable and smart cities.

The increase in demolition of the existing high-rise buildings and other crucial infrastructures has led to a substantial quantity of construction and demolition waste (CDW). The accumulation of these wastes raises concerns about the environmental balance, as these cause landfill overflows, increased carbon emissions, and increased construction requirements, which may lead to resource depletion. To address these concerns, the analysis of possibilities of recycling debris from CDW to address these concerns has resulted in the concept of RCA. RCA not only addresses the concern of managing CDW, but also the necessity for relying only on natural resources has reduced, which would prevent resource depletion, enhance circular economy, and serves as a sustainable alternative resource for construction purposes.

RCA refers to creating concrete aggregates from the CDW by processing it through various stages which include extraction, crushing, washing, screening, and sorting. Followed by this process, the resultant undergoes rigorous testing to ensure that it meets the quality standards. The approach leads to the development of valuable, sustainable, and recycled resources for constructing various types of infrastructure by transforming the CDW. The advanced material processing techniques have even resulted in the development of producing RCA with qualities that align with the natural aggregates and even exceed the expectations in some cases, which makes them employable to create aggregates for high-performance concrete applications. RCA would result in reduced ecological impact, minimizing the greenhouse gas emissions and carbon footprint associated with the transportation and extraction of natural aggregates. Despite the benefits of RCA, there are concerns of equipment and high energy utilization, which includes both fossil fuels based, and electrical energy based. This is because RCA demands rigorous processing, which includes specialized equipment for the production process.

The development and integration of energy efficient technologies for the purposes of RCA production process becomes essential. This would include replacing the diesel-powered machinery with energy efficient electric power machinery, also in considering IoT based monitoring systems would ensure, RCA production process becomes more environmentally friendly and sustainable process, adding value to its end-user (RCA) products and addressing UN – SDG11, Sustainable cities and communities; SDG12, Responsible consumption and production; SDG 9, Industry, innovation and infrastructure and SDG 17, Partnerships for the Goals that emphasis the necessity of the adopting process like RCA.

The advancements in renewable energy technology, which include solar PV systems, wind energy generation systems, and biomass generation, could be used for the RCA production process to energize the system (solar and Wind), and/or recycle the debris (biomass generation) at the CDW collection site. This would reduce the dependency on the relying on fossil fuels for powering the equipment involved in manufacturing RCA products. As an additional and more innovative approach, vibration-based energy harvesters shall be employed to generate electrical energy, as most of the stages of the production process generate enormous vibrations during the process. This would further optimize energy dependencies and escalate the RCA production process towards eco-friendlier and more sustainable, in terms of the production process and the products developed.

The rest of the article is segmented as section 2 briefing the RCA Production Process, followed by section 3 which deal with the equipment involved in RCA production process, then section 4 that deals with Energy Efficiency in RCA Production Process then section 5 Power Electronics in Enhancing Energy Efficiency and Sustainability of RCA Production Process which is followed by section 6 Renewable Energy Sources for RCA Production and section 7 on Energy Harvesting from the RCA Production Process before the conclusion in section 8.

## 2 RCA Production Process

The process of converting/transforming the construction and demolition waste (CDW) into usable RCA is carried out by the following sequential stages/process, starting from (1) Extraction/collection of CDW, (2) primary crushing, (3) screening, (4) secondary crushing, (5) washing and sorting, and (6) stockpiling and distribution [1]. Fig. 1 shows the aforementioned processes and Fig. 2 shows the sequence of the processes and is briefed in the following section.


**Fig. 1.** RCA Production Process

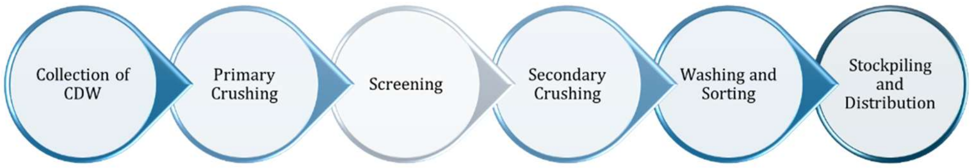


**Fig. 2.** Sequence of the Process

### 2.1 Extraction/Collection of CDW:

This stage involves the extraction and collection of CDW from the demolition site in a manner that ensures to preserve the quality of the debris (old concrete and other materials), which is then processed accordingly.

### 2.2 Primary crushing:

This is the second and one of the important stages of the process, in which the bulky concrete structures are fragmented into smaller and finer particles that can be managed/handled more easily. Impact crushers and jaw crushers are generally employed for this purpose.

### 2.3 Screening:

Primary crushing is followed by a screening process, where the fragmented aggregates are segregated based on their size which enables the collection/grouping of similar-sized materials that can be employed for suitable construction applications based on their size.

### 2.4 Secondary Crushing:

The fragments of the aggregates that do not meet the application requirements in the screening process undergo through the crushing process again, this is known to be the secondary crushing process. The secondary crushing process ensures that the aggregates are further fragmented into usable aggregates. The secondary crushing process involves cone crushers or additional impact crushers for the purpose of fragmenting the aggregates.

### 2.5 Washing and Sorting:

This process is very crucial for ensuring the purity and quality of the aggregates for making the aggregates worthy for high-grade concrete production. The contaminants present in the fragmented aggregates are cleaned with water-based systems. The contaminants could be dirt, dust, or other impurities that would degrade the quality of the aggregates.

### 2.6 *Stockpiling and Distribution:*

Stockpiling until distribution for appropriate/new construction project is also considered as a part of the RCA production process, since proper storing mechanism/methodology is essential to prevent contamination of the aggregates, as flaws in it would lead to quality degradation of the aggregates.

## 3 Equipment involved in RCA Production Process

The equipment involved in processing the RCA is similar to that of the natural aggregate processing, and the equipment involved for processing aggregates at different stages is shown in Fig. 3 [2]. To start with, the extraction/collection of CDW, excavators, and loaders are the prime equipment employed. If the extraction is to be done from the riverbed or if it is marine aggregate extraction, then a dredger comes into the picture in addition to excavators and loaders in the extraction phase of the RCA process.

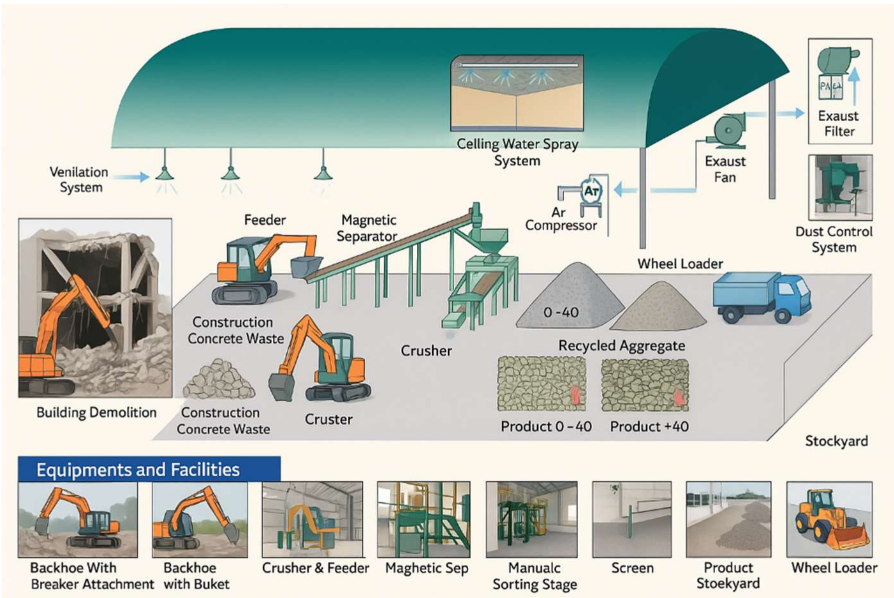


**Fig. 3.** Manufacturing process of recycled concrete aggregates and the equipment used in the process.

The primary crushing involves jaw crushers, Gyratory Crushers, and Impact Crushers. The secondary crushing stage involves cone crushers and ham mills for fragmenting the aggregates. The intermediate process between primary and secondary crushing is the screening process, which employs Vibratory Screens and Trommel Screens for categorizing aggregates. Log Washers, Sand Classifiers (Screw classifiers/Hydro cyclones), and Dewatering Screens are the equipment housed for the purpose of washing and sorting the contaminations of the aggregates. Stockpiling generally makes use of the belt conveyors and stackers in addition to bins and hoppers.

The equipment for both natural aggregate processing and recycled aggregate processing may be similar. However, specific configurations and settings are to be adjusted/tuned to suit the appropriate handling of the recycled aggregates based on their unique characteristics.

## 4 Energy Efficiency in RCA Production Process

The conventional aggregate production process involves crushers and conveyors which are diesel-powered. Fig. 4 shows the production process, and the type of energy used for the process[3]. Transforming these diesel-powered machinery to electric-powered machinery would be the first part of the energy efficiency in the RCA production process, which would also result in reduced greenhouse emissions and enhanced efficiency, and less wear and tear compared to diesel-powered machinery.

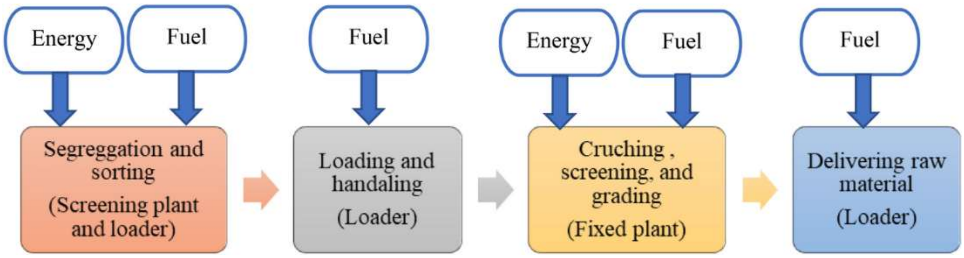


**Fig. 4.** Production Process of RCA.

Employing variable frequency drives (VFDs) will enhance speed control of these electrified machinery; also, considering multi-level inverters-based power supplies for these VFDs will result in reduced harmonic distortion, improving energy efficiency and enabling better grid stability.

Along with the aforementioned machinery modifications, implementing IoT-based monitoring[4] of the RCA production process and AI-based real-time data analytics can assist in AI-driven predictive analysis combined with smart grid integration. These enable optimized power flow and energy distribution in the aggregate production stages/plants.

Other measures for improving energy efficiency include the usage of carbon capture and utilization (CCU) technologies that capture the CO2 emissions from the crushing processes which can be used for curing concrete, enhancing the material properties and reducing carbon emission, employing supplementary cementitious materials (SCMs) could reduce carbon embodied in RCA based concrete green hydrogen could be considered for the thermal energy generation which is a sustainable alternative for high-energy processes. Fuel cell technology is a viable source of hydrogen energy generation and could result in hydrogen powered aggregate production plants.

Water management plays a significant role in enhancing energy efficiency, recycling the water used in the washing stage in terms of aggregate washing and dust removal, rainwater harvesting in production plants, and using VFD-based smart water pumps to enhance water management further. In addition to the above, sludge from the washing process, on appropriate processing, can be transformed into usable byproducts such as fine aggregates, resulting in waste minimization and maximizing material utilization.

Digital and smart manufacturing techniques of the AI era are a boon for the purpose of enhancing energy efficiency. AI-based operational and predictive maintenance models would assist in reducing energy usage and improving equipment lifespan. Also, blockchain technology, if employed, will ensure transparency in the aggregate production process, enabling carbon footprint assessments, optimizing energy utilization, and verifying the plants' sustainability.

# 5 Power Electronics in Enhancing Energy Efficiency and Sustainability of RCA Production Process

The technological advancements in electric motor drives, power electronic converters, and automation have deep-rooted the energy efficiency enhancement in almost all engineering equipment, which could be domestic appliances, industrial grade equipment, military or even aerospace equipment, resulting in reduced energy utilization and enhanced performance to improve the process in which it is being employed. These technological advancements also have intruded into RCA production process concerning energy efficiency and sustainability. There are three key areas in which these contribute to enhancing the energy efficiency process and sustainability:

(1) Optimizing Electric motors in crushers and conveyors, the power converters and drive technology aids in controlling the speed and torques of the electric motors employed in the crushers and conveyors, this way the energy utilization can be optimized resulting in energy saving and reduced operational costs.

(2) Regulating power in renewable energy-driven washing plants, power electronic converters have become an inevitable part of any power supply or power management system, especially renewable energy systems, where they act as the soul of the system. The renewable energy-based washing station will improve the process station's sustainability; if the renewable energy source is water-based, then the water source can also be used for the washing plant, improving the plant efficiency at a reduced operation cost and zero emission[5].

(3) Smart grid connectivity for energy management: The smart grid enables real-time monitoring and management of energy consumption, and the integration of the RCA production process with the smart grid is seamlessly facilitated by power converters, switching networks, and their automation.

## 5.1 Power Electronic Converters involved in RCA Production Process

Power electronic converters play a crucial role in integrating renewable energy sources and RCA production in the context of effective power conversion and optimized energy distribution/utilization ensuring grid stability.

A few key converters that could be employed for the purpose include DC-DC converters to regulate voltage and power flow in solar PV-based systems, DC-AC converters for converting the stored DC power to usable AC source for supplying the RCA processing equipment, AC-DC converters for energy storage and processing equipment in case of wind and hydro based energy generation, and bi-directional converters which allow efficient energy exchange between the sources, RCA equipment and energy storage units. In addition to these, variable frequency drives are key power electronic devices that find their employability in speed control applications of the motors used in conveyors, crushers, and pumps, resulting in reduced energy consumption.

# 6 Renewable Energy Sources for RCA Production

Fossil fuels have been the prime source of electrical energy generation along the side of hydropower generation over the past century; depletion of the availability of fossil fuel resources has led to a search for alternative solutions[6]. Nuclear power plants emerged as a key alternative in the 1950s from Russia. The energy generated by it was comparatively extensively enormous for the raw material used. Still, the slug of these power plants is toxic, and disposal becomes most tragic, where the necessity for clean and renewable energy generation has blossomed. From that point since, nations across the globe began the quest for such clean and renewable energy generation methods, resulting in key renewable energy generation methods, including solar PV, wind energy, and biomass-based energy in addition to the hydro-powered generation, which has existed since the 1870s[7]. Geothermal energy generation and hydrogen-fuel cell based energy generation are other two key energy generation which are clean form of energy generation having comparatively less contribution to the current energy requirements[8]. Fig. 5. depicts the share of renewable in the total global consumption as on 2021, this is keep increasing year on year as the installed capacity is increasing accordingly[9].

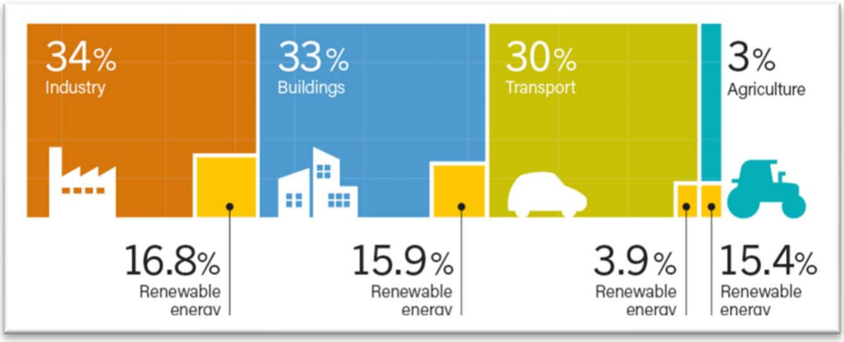


**Fig. 5.** Renewable energy share in the total global consumption by various sectors as on 2021.

Among the various aforementioned sources of clean and renewable energy generation, few can be more effectively employed for the RCA production process based on different grounds. The few include solar energy generation, wind power, and biomass-based generation[10]. A hybrid method of energy generation combining these can also be adopted based on the geography of the production plant, forming a microgrid that enables effective power generation from these sources.

Solar photovoltaic based power generation systems[11] can effectively be used for the primary and secondary crushing processes along with screening and washing processes. The energy generation can be maximized implementing maximum power point tracking and enhanced by incorporating appropriate power electronic converter topologies to optimize energy transfer and storage when there is excess power production.

The geographic locations with extensive wind potential may employ wind-based energy generation or a hybrid generation along with solar to have a consistent power generation to ensure a smooth integration with a grid connected or off grid production plant[12].

On the other hand, biomass-based energy generation can support the RCA production processes in multiple ways. One be the power generation for the electrified RCA production plants, and the other be the gasification and anerobic digestion[13] of the organic (wood and biodegradable) materials that are collected from the debris of the demolition site resulting in maximizing the recycling process of the debris.

## 7 Energy Harvesting from the RCA Production Process

Irrespective of the process stage, in addition to the usage of power electronic converters, renewable energy sources, and smart grid for energy enhancement and sustainability of the RCA process, vibration is one common aspect that occurs in all these processes, and the level of these vibrations are extreme in some of the process involved.

Vibration-based Electric energy generators are one of the alternative energy-generating methods that the globe is taking seriously[14] in the recent years. The Fig. 6. shows an illustration of the magnetic energy harvester that generates electrical energy from vibrations[15]. Some countries have already installed vibration based electric generators in pedestrian paths for energy generation and generating considerable amount of energy over the years.

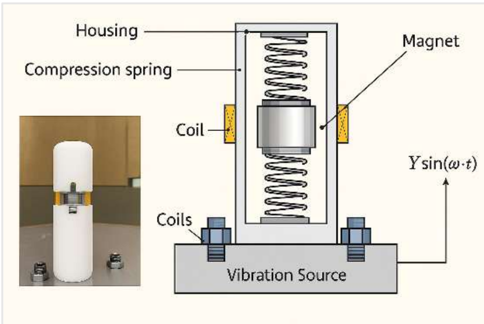


**Fig. 6.** Illustration of vibration-based electromagnetic energy harvester.

The availability of these generators and ease of implementing feasibility is also increasing day by day across the globe, focusing on sustainability and clean energy generation and cutting out emissions, possibly aiming at zero emissions. In such a scenario, the process stages of RCA production are a great source of vibrations; with appropriate design and planning, considerable energy can be generated in each process, which could even electrify the process itself.

## 8 Conclusion

The RCA production from CDW is a more significant progress towards sustainability in the case of the construction industry as it converts the CDW waste into reusable products and reduces dependency on natural aggregates without compromising the quality. This is a progressive step towards a circular economic approach and environmentally friendly products, conserving natural resources in the era, focusing more on sustainability due to the faster depletion rate of natural resources, due to an extreme increase in consumption. However, the manufacturing process of RCA products does include numerous rigorous processes which require specialized equipment, resulting in concern of energy requirements and carbon footprint offsetting benefits towards sustainability.

Incorporation of renewable energy systems, wind, solar PV, and biomass along with the power-electronic technologies such as variable frequency drives and multilevel inverters, sets an alternate for the concern. This is achieved by shifting the manufacturing equipment energy requirement from diesel-based equipment to energy-efficient electric drives, reducing the carbon footprint caused by the RCA manufacturing process. The incorporation of biomass generation for effective usage of the combustible debris from the CDW adds value to the goal of progressing towards a sustainable production process. Furthermore, IoT-based monitoring and AI-driven analytics optimize the RCA production process, ensuring predictive maintenance, real-time energy management, and operational transparency.

The innovative ideology of generating energy from the vibrations caused during the manufacturing process through a vibration energy harvester is another opportunity for converting the mechanical waste into usable energy. Overall, these approaches make the RCA production process a low-impact and high-performance solution than a mere waste management and recycling process, paving the way to greener and efficient RCA production. Collectively, this approach aligns with multiple UN sustainable goals: SDG11, Sustainable cities and communities; SDG12, Responsible consumption and production; SDG 9, Industry, innovation and infrastructure, and SDG 17, Partnerships for the Goals that emphasize the necessity of the adopting process like RCA.

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## References

1. D. Suarez-Riera et al., An Overview of Methods to Enhance the Environmental Performance of Cement-Based Materials, Infrastructures, **9**, 94, (2024), 10.3390/infrastructures9060094.
2. W. Kittinaraporn, S. Tuprakay, and L. Prasittisopin, Effective Modeling for Construction Activities of Recycled Aggregate Concrete Using Artificial Neural Network, J. Constr. Eng. Manage, **148**, 04021206, (2022), 10.1061/(ASCE)CO.1943-7862.0002246.
3. A. Younes, E. Elbeltagi, A. Diab, G. Tarsi, F. Saeed, and C. Sangiorgi, Incorporating coarse and fine recycled aggregates into concrete mixes: mechanical characterization and environmental impact, J Mater Cycles Waste Manag, **26**, 654–668, (2024), 10.1007/s10163-023-01834-1.
4. P. Santhosh, G. Kathiravan, M. Jayaram, M. Deepanraj, L. Ajhai Kumar, and N. Devipriya, IoT Based Supervisory and Diagnosis System for Solar Farm, in 2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India: IEEE, (2023), 914–918. 10.1109/ICACCS57279.2023.10112993.
5. A. T. Mossie, D. Khatiwada, B. Palm, and G. Bekele, Energy demand flexibility potential in cement industries: How does it contribute to energy supply security and environmental sustainability?, Applied Energy, **377**, 124608, (2025), 10.1016/j.apenergy.2024.124608.
6. J. Wang and W. Azam, Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries, Geoscience Frontiers, **15**, 101757, (2024), 10.1016/j.gsf.2023.101757.
7. C. S. Kaunda, C. Z. Kimambo, and T. K. Nielsen, Hydropower in the Context of Sustainable Energy Supply: A Review of Technologies and Challenges, ISRN Renewable Energy, **2012**, 1–15, (2012), 10.5402/2012/730631.
8. H. Om, A. Sircar, T. Gautam, K. Yadav, and N. Bist, Comprehensive review of hydrogen generation utilizing geothermal energy, Unconventional Resources, **5**, 100109, (2025), 10.1016/j.uncres.2024.100109.
9. REN21, Renewables 2024 Global Status Report – Energy Demand module, (2024) https://www.ren21.net/renewables-2024-global-status-report-energy-demand-module/
10. F. Ali et al., Fueling the future: biomass applications for green and sustainable energy, Discov Sustain, **5**, 156, (2024), 10.1007/s43621-024-00309-z.
11. S. Paramasivam, A. Majumder, A. S., G. Cappellini, A. Kumar, and G. Gatto, Optimizing Solar Energy Harvesting: A Comparative Study of PV Panel Performance Through Mathematical Modeling and Real-Time Analysis in Variable Ambient Conditions, in 2024 Second International

Conference on Intelligent Cyber Physical Systems and Internet of Things (ICoICI), Coimbatore, India: IEEE, 594–600, (2024). 10.1109/ICoICI62503.2024.10696350.

12. K. Ullah et al., Wind Farms and Flexible Loads Contribution in Automatic Generation Control: An Extensive Review and Simulation, Energies, **16**, 5498, (2023), 10.3390/en16145498.
13. D. J. Prasanna Kumar, R. K. Mishra, S. Chinnam, P. Binnal, and N. Dwivedi, A comprehensive study on anaerobic digestion of organic solid waste: A review on configurations, operating parameters, techno-economic analysis and current trends, Biotechnology Notes, **5**, 33–49, (2024), 10.1016/j.biotno.2024.02.001.
14. H. M. Ouakad, Vibration-Based Energy Harvesters: New Ways to Scavenge Energy, Energies, **16**, 5019, (2023), 10.3390/en16135019.
15. M.-C. Chiu, Y.-C. Chang, L.-J. Yeh, and C.-H. Chung, Numerical Assessment of a One-Mass Spring-Based Electromagnetic Energy Harvester on a Vibrating Object, Archives of Acoustics, **41**, 119–131, (2016), 10.1515/aoa-2016-0012.