

---

## **SOLAR ENERGY AND THE ENVIRONMENT: A REVIEW OF SOLAR CELL LIFECYCLES**

**Dr. Ravi Shankar Kumar,**

Assistant professor, Department of physics, S P CollegeDumka, Jharkhand, Pin 814101.

Email: [ravishankarkumar4569@gmail.com](mailto:ravishankarkumar4569@gmail.com)

**Abstract:** This review explores the environmental impacts of solar cells throughout their entire lifecycle, from raw material extraction to end-of-life disposal. Solar energy, widely regarded as a key solution to the global energy crisis and climate change, offers significant benefits in terms of reducing greenhouse gas emissions. However, the production, installation, and disposal phases of solar cells present environmental challenges that must be understood to ensure the overall sustainability of solar technology. This review assesses the ecological footprint of solar cells by examining resource extraction, manufacturing processes, energy consumption, pollution, and waste management. It highlights the trade-offs associated with different types of solar cells, including silicon-based, thin-film, and emerging technologies. The review also explores mitigation strategies, such as sustainable material sourcing and advanced recycling techniques, to address environmental concerns. By providing a comprehensive analysis of the lifecycle impacts of solar cells, this review aims to inform stakeholders and guide improvements in solar technology, ultimately supporting the transition to a more sustainable and environmentally friendly energy system.

**Keywords:** Solar Cells, Lifecycle Assessment, Environmental Impact, Renewable Energy, Resource Extraction, Waste Management, Sustainability

### **Introduction:**

Solar energy stands at the forefront of renewable resources, offering a compelling solution to the global energy crisis and climate change. As the world grapples with the effects of fossil fuel consumption, solar energy has emerged as a cleaner, more sustainable alternative. The technology harnesses the sun's energy through photovoltaic (PV) cells, converting sunlight directly into electricity [1]. This process not only reduces reliance on finite resources but also mitigates greenhouse gas emissions. With advancements in solar technology, including various types of solar cells such as silicon-based and thin-film, the efficiency and applicability of solar energy systems have significantly improved. However, the growth of solar energy adoption also brings to light the need to evaluate the full environmental impact of solar cells, beyond their operational phase.

Understanding the environmental impact of solar cells is crucial as the technology becomes increasingly widespread. While solar energy is celebrated for its low emissions during operation, the production and disposal phases of solar cells involve complex processes that can have significant ecological footprints [2]. The lifecycle of solar cells encompasses raw material extraction, manufacturing, installation, maintenance, and eventual disposal or recycling. Each of these stages carries potential environmental impacts, from resource depletion and energy



consumption to pollution and waste management issues. As solar technologies continue to evolve, it is essential to comprehensively assess these impacts to ensure that the overall environmental benefits outweigh the drawbacks and to guide improvements in technology and practices.

The objective of this review is to provide a thorough examination of the lifecycle of solar cells and evaluate their environmental impact throughout each phase. By analyzing the entire lifecycle—from the extraction of raw materials to the disposal of end-of-life products—this review aims to offer a holistic understanding of the environmental implications associated with solar energy systems [3]. The goal is not only to highlight the benefits of solar energy but also to identify areas where improvements can be made to minimize environmental harm. This comprehensive approach will help stakeholders, including policymakers, manufacturers, and consumers, make informed decisions about the adoption and development of solar technology, ultimately contributing to a more sustainable energy future.

### **Solar Cell Technologies:**

Solar cell technologies have evolved significantly over the past decades, with various types now available to meet different energy needs and application scenarios. The most prevalent technology remains silicon-based solar cells, which come in three primary forms: monocrystalline, polycrystalline, and amorphous. Monocrystalline silicon cells are renowned for their high efficiency and longevity. Made from a single continuous crystal structure, these cells offer a high-power output per square meter and are often used in residential and commercial solar installations where space is limited. Polycrystalline silicon cells, on the other hand, are composed of multiple silicon crystals melted together [4]. Although they have a slightly lower efficiency compared to monocrystalline cells, they are less expensive to produce and are widely used in large-scale solar farms. Amorphous silicon cells, which use a non-crystalline form of silicon, are flexible and lightweight, making them suitable for a variety of applications including integration into building materials and consumer electronics. However, their lower efficiency and shorter lifespan make them less ideal for large-scale power generation.

In addition to silicon-based technologies, thin-film solar cells represent a significant advancement in solar technology. These cells are produced by depositing one or more thin layers of photovoltaic material onto a substrate, which can be flexible and lightweight. Among the various thin-film technologies, Cadmium Telluride (CdTe) cells are known for their low production costs and good performance in low-light conditions, making them suitable for large-scale solar power plants. Copper Indium Gallium Selenide (CIGS) cells offer higher efficiency compared to CdTe cells and can be produced on flexible substrates, providing versatility in application [4]. Organic Photovoltaics (OPV), another type of thin-film technology, use organic materials to convert light into electricity. While OPVs are still in the research and development phase and have relatively lower efficiency, they promise potential advantages such as low-cost production and flexibility, which could open up new application possibilities in the future.

Emerging technologies in solar cells are paving the way for the next generation of photovoltaic systems. Perovskite solar cells have garnered significant attention due to their high efficiency and relatively low production costs [5]. These cells use a class of materials called perovskites, which have demonstrated impressive light absorption and charge-carrier properties. Although stability and scalability remain challenges, ongoing research aims to address these issues and



potentially revolutionize the solar industry. Quantum Dot Solar Cells represent another exciting advancement. These cells utilize nanometer-sized semiconductor particles, or quantum dots, to capture light more effectively and enhance efficiency. The tunable bandgap of quantum dots allows for better absorption of various wavelengths of light, potentially leading to higher overall efficiency. As research continues to evolve, these emerging technologies hold the promise of significantly improving solar energy conversion and expanding the applications of solar power.

### **Lifecycle Stages of Solar Cells:**

#### **A. Raw Material Extraction:**

The lifecycle of solar cells begins with the extraction of raw materials, a critical phase that lays the groundwork for their production and ultimately affects their environmental impact. The primary material for most solar cells is silicon, which is extracted from silica (sand) through a process that involves mining and refining. This process requires significant energy input and can result in considerable environmental disturbances, such as habitat destruction and water pollution. Mining operations, particularly for materials like cadmium and tellurium used in thin-film solar cells, can lead to soil erosion and contamination of water sources [6]. Additionally, the extraction of rare metals, such as indium and gallium, which are crucial for certain types of thin-film and emerging solar technologies, often involves complex and environmentally taxing procedures. The mining and processing stages are resource-intensive, contributing to ecological degradation and carbon emissions, which underscores the need for more sustainable practices in the extraction of these materials.

#### **B. Manufacturing:**

Once raw materials are obtained, the manufacturing stage transforms them into functional solar cells. This stage is characterized by its substantial energy and resource consumption. For instance, the production of silicon-based solar cells involves several energy-intensive steps, including the purification of silicon, the creation of silicon wafers, and the assembly of cells into modules. These processes contribute to greenhouse gas emissions, primarily due to the electricity used, which often comes from non-renewable sources. Moreover, the manufacturing of solar cells generates waste materials, such as silicon cuttings and chemical by-products, which require careful disposal to mitigate environmental harm. The generation of these wastes and emissions during the fabrication of solar cells can be significant, emphasizing the importance of adopting cleaner production technologies and improving waste management practices to minimize their environmental footprint [7].

#### **C. Installation:**

The installation of solar cells further impacts the environment through various means. The process of installing solar panels involves land use and potentially disrupts local ecosystems. Large-scale solar farms require significant land area, which can lead to habitat loss and changes in land use patterns. Additionally, the installation process itself can be resource-intensive, involving the transportation of panels, mounting structures, and associated infrastructure. While the direct environmental impact of installation is generally less than that of manufacturing, it still poses challenges, particularly in areas where sensitive ecosystems are present. Proper site selection and careful planning are crucial to minimizing the ecological footprint of solar



installations, ensuring that they do not adversely affect local flora and fauna or lead to soil erosion and other forms of environmental disruption.

#### **D. Operation and Maintenance:**

During the operational phase, solar cells typically have a lower environmental impact compared to other energy sources, as they produce electricity without direct emissions. However, their efficiency and energy yield can be influenced by environmental factors such as dust, dirt, and shading, which may necessitate periodic maintenance. Maintenance practices, such as cleaning and repairs, must be conducted with consideration for their environmental impact. The use of water for cleaning solar panels, for instance, can be a concern in arid regions where water resources are scarce [8]. Additionally, while solar panels generally have long lifespans, occasional component replacements or repairs are necessary. These maintenance activities should be managed in a way that minimizes their environmental footprint and maximizes the efficiency and longevity of the solar systems.

#### **E. End-of-Life and Disposal:**

The end-of-life phase of solar cells presents unique challenges and opportunities for environmental management. As solar panels reach the end of their operational life, they must be decommissioned and either recycled or disposed of. Recycling processes for solar cells can be complex due to the diverse materials used in their construction, such as silicon, metals, and various coatings. Effective recycling strategies are essential to recover valuable materials and reduce waste. However, the presence of hazardous substances, such as cadmium in some thin-film technologies, poses additional risks if not managed properly. Ensuring safe and efficient disposal methods is crucial to prevent environmental contamination. Innovations in recycling technologies and improved waste management practices are necessary to address these challenges and enhance the sustainability of solar energy systems throughout their entire lifecycle.

### **Environmental Impacts:**

#### **A. Carbon Footprint:**

The carbon footprint of solar cells encompasses the greenhouse gas emissions associated with their entire lifecycle, from raw material extraction to end-of-life disposal. During the manufacturing phase, significant emissions arise primarily due to the energy-intensive processes involved in purifying silicon and fabricating solar cells. However, once installed and operational, solar cells themselves produce no direct emissions, which contrasts sharply with fossil fuel-based energy sources. Studies have shown that the carbon footprint of solar energy is considerably lower compared to conventional energy sources like coal and natural gas [9]. For instance, while the production of solar panels generates greenhouse gases, the energy they generate over their operational lifetime leads to a substantial reduction in overall emissions. Solar panels can offset their production-related emissions within a few years of operation, and their low carbon intensity during operation underscores their potential to contribute to a low-carbon energy future.

#### **B. Resource Depletion:**

The extraction of raw materials for solar cells, such as silicon, cadmium, and rare metals like



indium and gallium, impacts natural resources and raises concerns about material scarcity. Silicon, used in the majority of solar cells, is abundant, but its purification process requires significant energy and resources. In contrast, materials used in thin-film and emerging technologies are less abundant, raising concerns about their long-term availability. For example, cadmium, used in CdTe thin-film cells, and indium, used in CIGS cells, are relatively rare and involve mining practices that can contribute to resource depletion. The increasing demand for these materials, driven by the growth in solar energy adoption, necessitates sustainable practices to manage resource use effectively. Strategies such as recycling and exploring alternative materials are essential to mitigate the risk of depletion and ensure the long-term sustainability of solar technology.

### **C. Pollution:**

The production and disposal of solar cells contribute to various forms of pollution, which need to be carefully managed to minimize environmental harm. During manufacturing, pollutants can be released into the air and water, including toxic chemicals used in the production processes. For instance, the use of cadmium and other heavy metals in some types of thin-film solar cells can pose environmental risks if not properly controlled. Additionally, the disposal phase of solar cells can result in the release of hazardous materials if recycling processes are inadequate [10]. Proper waste management practices are critical to prevent pollution and ensure that harmful substances do not leach into soil and water sources. Advancements in manufacturing technologies and stricter regulations are necessary to address these pollution issues and reduce the environmental impact of solar cell production and disposal.

### **D. Waste Management:**

Effective waste management is crucial for minimizing the environmental impact of solar cells, particularly at the end of their lifecycle. The recycling of solar panels can recover valuable materials, such as silicon and metals, but the process can be complex and costly. Current recycling programs face challenges, including the efficient separation of materials and the handling of hazardous substances. Despite these challenges, recycling remains an essential strategy for managing solar cell waste and reducing the reliance on virgin materials. Innovations in recycling technologies, such as improved sorting methods and chemical processes, are helping to enhance the effectiveness of recycling programs [11]. Additionally, designing solar panels with end-of-life recycling in mind and implementing take-back programs can further support sustainable waste management. Addressing these challenges is vital for ensuring that solar energy remains a sustainable and environmentally friendly option as the technology continues to advance.

## **Mitigation Strategies:**

### **A. Sustainable Material Sourcing:**

Sustainable material sourcing is crucial for reducing the environmental impact of solar cells and ensuring their long-term viability. One approach is to use less harmful materials in the production of solar cells. For example, replacing hazardous substances like cadmium with more environmentally benign alternatives can significantly lower the potential for pollution and resource depletion. Additionally, improving mining practices is essential to minimize environmental damage. This includes adopting methods that reduce soil erosion, water contamination, and habitat destruction. Techniques such as improved waste management, land





reclamation, and more efficient resource extraction can mitigate the negative effects associated with mining activities. By focusing on sustainable material sourcing, the solar industry can decrease its environmental footprint and contribute to a more sustainable energy future.

### **B. Energy-Efficient Manufacturing:**

Energy-efficient manufacturing plays a key role in reducing the carbon footprint and overall environmental impact of solar cells. The production of solar cells is energy-intensive, and adopting cleaner production technologies can help lower energy consumption and emissions. Innovations such as using renewable energy sources to power manufacturing facilities, improving energy efficiency in production processes, and reducing material waste are essential strategies. For instance, advancements in fabrication techniques, like the development of low-energy processes for silicon purification and cell assembly, can significantly cut down the energy requirements. Additionally, implementing energy management systems and optimizing production workflows can further enhance efficiency. By prioritizing energy-efficient manufacturing, the solar industry can decrease its environmental impact and move towards more sustainable production practices.

### **C. Enhanced Recycling Technologies:**

The advancement of recycling technologies is crucial for managing the waste generated by solar cells and recovering valuable materials. Enhanced recycling techniques can address challenges such as the efficient separation of materials and the handling of hazardous substances. Recent developments in recycling technologies include improved mechanical and chemical processes that allow for better recovery of silicon, metals, and other components from end-of-life solar panels. Innovations such as hydrometallurgical methods and advanced separation technologies can increase the efficiency and effectiveness of recycling operations. Furthermore, investing in recycling infrastructure and creating closed-loop systems where recovered materials are reintegrated into the production process can reduce waste and resource consumption. By advancing recycling technologies and infrastructure, the solar industry can mitigate the environmental impact of solar cell disposal and support the sustainability of solar energy systems.

### **D. Lifecycle Assessment Tools:**

Lifecycle assessment (LCA) tools are instrumental in evaluating and minimizing the environmental impacts of solar cells throughout their lifecycle. These tools provide a comprehensive analysis of the environmental impacts associated with each stage of a solar cell's lifecycle, from raw material extraction to disposal. By using LCA tools, stakeholders can identify areas where environmental impacts are most significant and develop targeted strategies to address them. For example, LCA can help assess the trade-offs between different materials and technologies, guiding decisions towards more sustainable options. Additionally, LCA tools can support the development of best practices and policies for minimizing environmental impacts, such as optimizing resource use and reducing emissions. As the solar industry continues to grow, the use of lifecycle assessment tools will be essential for driving improvements in environmental performance and ensuring the sustainability of solar energy technologies.

## **Case Studies:**

### **A. Case Study 1: Silicon-Based Solar Cells:**

Silicon-based solar cells are among the most widely used photovoltaic technologies, and their



environmental impact has been extensively studied through lifecycle analysis. These cells, primarily available in monocrystalline, polycrystalline, and amorphous forms, involve significant environmental considerations from material extraction to disposal. The lifecycle of silicon-based solar cells begins with the extraction and processing of silicon, which requires substantial energy and can result in greenhouse gas emissions. The purification process for silicon is particularly energy-intensive, contributing to the carbon footprint of these cells. However, once operational, silicon-based solar cells offer a substantial reduction in greenhouse gas emissions compared to fossil fuel-based energy sources. The efficiency and durability of silicon cells also translate to long-term benefits, as they typically have longer lifespans and require less frequent replacement. Despite these advantages, the end-of-life phase presents challenges, including the need for effective recycling methods to handle silicon waste and recover valuable materials. Overall, while silicon-based solar cells have a notable environmental footprint during production, their long-term benefits in reducing operational emissions make them a key technology in the transition to renewable energy.

### **B. Case Study 2: Thin-Film Solar Cells:**

Thin-film solar cells, including those made from cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and organic photovoltaics (OPV), offer a different environmental profile compared to silicon-based cells. These technologies typically involve lower material costs and can be produced using less energy, which can reduce their overall carbon footprint. CdTe cells, for example, are known for their relatively low production costs and good performance in low-light conditions. However, the use of cadmium, a toxic heavy metal, poses significant environmental and health risks if not properly managed during production and disposal. CIGS cells, while more efficient than CdTe, also involve rare materials, raising concerns about resource depletion and scarcity. OPVs, still in the experimental phase, promise lower environmental impact due to their use of organic materials, but their commercial viability and long-term performance remain uncertain. Lifecycle assessments of thin-film technologies highlight a complex balance between lower initial energy inputs and potential environmental hazards associated with material use and disposal. As these technologies continue to develop, addressing issues related to material toxicity and resource management will be crucial for minimizing their environmental impact.

### **C. Case Study 3: Emerging Technologies:**

Emerging solar technologies, such as perovskite and quantum dot solar cells, present both exciting potential and environmental concerns. Perovskite solar cells have shown remarkable efficiency improvements and lower production costs due to their simple manufacturing processes. However, their long-term stability and the potential for lead contamination are significant concerns. Research is ongoing to develop lead-free perovskites and improve the durability of these cells to mitigate potential environmental risks. Quantum dot solar cells, utilizing nanometer-sized semiconductor particles, offer the advantage of tunable bandgaps, which could lead to higher efficiencies and new applications. Yet, the synthesis and handling of quantum dots involve complex processes that may introduce environmental and health risks if not carefully managed. Both perovskite and quantum dot technologies are in advanced research stages, and while they promise substantial benefits, their commercial adoption will require addressing environmental concerns related to material use and lifecycle impacts. Continued research and development are essential to ensure these emerging technologies contribute



positively to the renewable energy landscape while minimizing their environmental footprint.

### **Future Directions:**

#### **A. Innovations in Solar Cell Technologies:**

The future of solar cell technologies holds promising innovations that have the potential to significantly reduce their environmental impact. Advances in materials science are paving the way for the development of more efficient and sustainable solar cells. For example, next-generation perovskite solar cells and quantum dot technologies are at the forefront of this innovation. Perovskite cells are showing increased efficiency and lower production costs, and ongoing research is focused on addressing stability issues and reducing the use of hazardous materials like lead. Similarly, quantum dot solar cells offer the possibility of enhanced efficiency through their tunable bandgaps, though challenges related to the synthesis and handling of quantum dots must be overcome. Furthermore, the integration of bifacial solar panels, which capture sunlight from both sides, and the development of flexible and lightweight solar cells expand application possibilities and reduce the material footprint. Innovations in recycling technologies, such as improved methods for recovering valuable materials from end-of-life panels, also contribute to minimizing environmental impacts. As these technologies mature, their ability to offer high performance with lower environmental costs will play a crucial role in advancing the sustainability of solar energy.

#### **B. Policy and Regulation:**

Policies and regulations play a critical role in shaping the environmental sustainability of solar energy technologies. Government policies can incentivize the adoption of cleaner technologies and promote practices that reduce environmental impact. For instance, regulations that mandate the use of less hazardous materials in solar cell production or provide subsidies for the use of recyclable and sustainable materials can drive significant improvements in lifecycle sustainability. Policies that support research and development in solar technology and recycling infrastructure are also essential for fostering innovation and reducing environmental impacts. Additionally, implementing extended producer responsibility (EPR) schemes can ensure that manufacturers take responsibility for the end-of-life management of their products, encouraging the development of recycling programs and reducing waste. Effective policy frameworks and regulations not only help mitigate the negative environmental impacts of solar energy but also support the broader goal of transitioning to a more sustainable energy system by setting standards and providing incentives for continuous improvement.

#### **C. Research Needs:**

Ongoing research is crucial for addressing gaps and advancing the lifecycle sustainability of solar energy technologies. Areas requiring further investigation include improving the environmental performance of emerging technologies, developing more sustainable materials, and enhancing recycling processes. Research into alternative materials that can replace hazardous substances, such as lead in perovskite cells or cadmium in thin-film technologies, is essential for reducing environmental risks. Additionally, advancing the efficiency and durability of solar cells can extend their lifespan and reduce the frequency of replacements, thereby minimizing waste and resource use. Enhanced recycling technologies are also a key focus, as better methods for material recovery can reduce the environmental impact of solar cell disposal. Furthermore, lifecycle assessment tools and methodologies need continuous refinement to





accurately capture the environmental impacts of new technologies and practices. By addressing these research needs, the solar industry can drive innovations that contribute to a more sustainable and environmentally friendly energy future.

### **Conclusion:**

The environmental impact of solar energy technologies, while significantly lower than conventional fossil fuels, encompasses a range of considerations that span from raw material extraction to end-of-life disposal. As solar cells become increasingly integral to global efforts to transition to renewable energy, it is essential to address and mitigate their environmental footprint through comprehensive lifecycle management.

The lifecycle stages of solar cells—encompassing raw material extraction, manufacturing, installation, operation, and disposal—each present distinct environmental challenge. Raw material extraction, while foundational, often involves resource-intensive processes that can lead to habitat destruction and pollution. Manufacturing further compounds these issues with high energy consumption and emissions. However, the operational phase of solar cells is where the technology demonstrates its strength, significantly reducing greenhouse gas emissions compared to fossil fuels. Yet, the disposal phase introduces complexities, particularly with the management of waste and hazardous materials. Addressing these challenges requires targeted strategies and innovations to ensure that solar energy remains a truly sustainable option.

Mitigation strategies are critical in reducing the environmental impact of solar cells. Sustainable material sourcing, including the use of less harmful materials and improved mining practices, can help address issues related to resource depletion and pollution. Energy-efficient manufacturing processes that reduce emissions and resource use are also vital. Enhanced recycling technologies and effective waste management practices will be crucial for minimizing the impact of end-of-life solar cells and recovering valuable materials. Additionally, lifecycle assessment tools can guide decision-making by providing a comprehensive view of environmental impacts and highlighting areas for improvement.

Looking forward, the future of solar energy technologies holds significant promise for further reducing environmental impacts. Innovations in materials and manufacturing processes, such as the development of next-generation perovskite and quantum dot solar cells, offer the potential for higher efficiency and lower environmental costs. Policy and regulation play a pivotal role in promoting these advancements by incentivizing sustainable practices and supporting research and development. Effective policies can drive the adoption of cleaner technologies, improve recycling infrastructure, and encourage the use of sustainable materials.

Ongoing research is essential to address current limitations and explore new opportunities for enhancing the sustainability of solar energy. Key areas for research include developing alternative materials to replace hazardous substances, improving the efficiency and durability of solar cells, and advancing recycling technologies. By focusing on these areas, the solar industry can overcome existing challenges and drive progress towards a more sustainable and environmentally friendly energy system. While solar energy technologies represent a crucial component of the global transition to renewable energy, it is imperative to continuously assess and address their environmental impacts. Through innovative technologies, effective policies, and dedicated research, we can enhance the sustainability of solar energy and ensure its role as a cornerstone of a clean energy future.



## References:

1. Palaniappan, S. K., Chinnasamy, M., Rathanasamy, R., & Pal, S. K. (2021). Recycling of solar panels. *Materials for Solar Energy Conversion: Materials, Methods and Applications*, 47-86.
2. Pehnt, M., Bubenzer, A., & Räuber, A. (2003). Life cycle assessment of photovoltaic systems—trying to fight deep-seated prejudices. In *Photovoltaics Guidebook for Decision-makers: Technological Status and Potential Role in Energy Economy* (pp. 179-213). Berlin, Heidelberg: Springer Berlin Heidelberg.
3. Sabour, M. R., Jafari, M. A., & Hosseini Gohar, S. M. (2020). Si-based solar cells' conversion efficiency related publications bibliometric review during 2000-2017. *Silicon*, 12(11), 2705-2720.
4. Shukla, A. K., Sudhakar, K., & Baredar, P. (2016). A comprehensive review on design of building integrated photovoltaic system. *Energy and Buildings*, 128, 99-110.
5. Romero-Hernandez, S., Romero-Hernandez, O., Lindsay, C., Kingsbury, T., & Dornfeld, D. (2012). Supply Chain Life Cycle Implications of Shipping Goods from Mexico—A Case on PV Solar Panels. In *Leveraging Technology for a Sustainable World: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, University of California at Berkeley, Berkeley, USA, May 23-25, 2012* (pp. 605-610). Springer Berlin Heidelberg.
6. Kurdgelashvili, L., & Narbel, P. A. (2011). A Review of Solar Energy.
7. Brownson, J. R. (2013). *Solar energy conversion systems*. Academic Press.
8. Liyanage, C. M. K., Rupasinghe, C. P., Mahanama, G. D. K., & Abeywikrama, S. Designing and Analysis of Solar and Grid Connected Hybrid Electricity System for Domestic Use. In *National Energy Symposium* (p. 1).
9. Perez, M. J., & Fthenakis, V. (2011, June). A lifecycle assessment of façade BIPV in New York. In *2011 37th IEEE Photovoltaic Specialists Conference* (pp. 003271-003276). IEEE.
10. Elgowainy, A., Han, J., Ward, J., Joseck, F., Gohlke, D., Lindauer, A., ... & Wallington, T. (2016). *Cradle-to-grave lifecycle analysis of US light duty vehicle-fuel pathways: a greenhouse gas emissions and economic assessment of current (2015) and future (2025-2030) technologies* (No. ANL/ESD-16/7). Argonne National Lab.(ANL), Argonne, IL (United States).
11. Zwoniarkiewicz, S. (2017). *Life cycle design of a single family house in Poland—comparative study* (Doctoral dissertation, Technische Universität Wien).