Journal Of Research Technology & Engineering
www.jrte.org

Future of wind energy in Sri Lanka

* W.P. Madhushani Perera

Faculty of Technological Studies, Uva Wellassa University, Sri Lanka
* wpmpeshala@gmail.com

Received:02 July 2023; Revised: 05 July 2023; Accepted: 07 July 2023; Available online: 10 July 2023

Abstract: Day to day growing demand for electricity worldwide and the environmental consequences of conventional fossil fuel-based energy generation systems have intensified the need for sustainable alternatives for electricity generation. This paper examines the environmental impact and emission reduction strategies used in the construction, operational, and deconstruction phases of wind power plants, with a focus on the Sri Lankan context. The study reveals that the global electricity generation mix remains heavily reliant on fossil fuels, leading to substantial emissions of greenhouse gases and pollutants. This paper highlights the emission sources associated with wind power plant life cycle phases and various strategies are proposed to address these emissions. Furthermore, the study emphasizes the importance of conducting lifecycle assessments and implementing carbon offsetting programs to identify emissions hotspots and compensate for unavoidable emissions.

Index Terms: Electricity generation, Fossil fuels, Life cycle assessment, Renewable energy

1 Introduction

Conventional fossil fuels remain in the dominant world's electricity generation mix, becoming electricity the most feasible and adaptable form of energy obtained from primary sources. In 2018, the worldwide energy consumption quantity for electricity generation was primarily from oil (2.9%), coal (38.2%), and natural gas (23.1%). Hydroelectric power accounted for 15.8% of the mix, followed by nuclear energy at 10.2% and non-hydro renewables contributed a smaller portion of 9.8%. These statistics highlight the prevailing dependence on coal, natural gas, and hydroelectric power as the primary fuels for generating electricity [1].

The production and consumption of electricity are essential for meeting basic human needs as one of the major requirements and have significant environmental consequences. The strong reliance on fossil fuels for electricity generation has been becoming a major contributor to the huge emission of greenhouse gases (GHG), as well as pollutants like NO_x and SO_2. The utilization of fossil fuels is combined with a range of adverse environmental issues, including global warming, acid rain, smog, and groundwater pollution [2]. Based on the data gathered from Intergovernmental Panel on Climate Change (IPCC), global CO_2 equivalent emissions in electricity production are accountable for 37% [1]. With the aim of increasing global electricity demand by 43% by 2050, the adverse environmental consequences associated with fossil fuel-based electricity generation systems are expected to persist if current practices follow continuously for the generation of electricity.

Addressing the global energy demand and reducing environmental pollution requires the adoption of sustainable alternative energy sources. Renewable energies are crucial in reducing the environmental impact associated with electricity production [3]. The exploration of renewable and sustainable energy sources, such as hydroelectric, wind, and solar energy, has gained significant attention by today due to some specific features such as renewability. These sources offer promising solutions to combat environmental pollution and meet the growing day-to-day energy needs of the world.

2. CONDITION OF SRI LANKA

When considering the world's total electricity generation, Sri Lanka is a still developing country in the Asian region and showing significant growth in its electricity generation capacity over the years due to the increased population and human requirements. The demand can be seen in some fields such as domestic, industrial, and commercial since it is the most required and frequently used pre-requisite in those sectors for the majority of applications. When paying attention to the past few years, there has been a signification transformation in electricity generation in Sri Lanka from a system that is mostly hydroelectric to a system that is mixed hydrothermal. From the earliest times, hydropower was the major electricity generation method in Sri Lanka. But the problems are lying in changes that happened in rainfall patterns and other climatic conditions. Therefore, these reasons became a major reason to focus on other alternative technologies which provide sustainable electricity supply. As a solution, in 1992, the first coal-fired power plant was established in Trincomalee with a capacity of 300 MW. Afterwards, Sri Lanka shifted from hydropower generation systems to fossil fuel-based power generation systems and then it caused a steady improvement in CO_2 emissions per capita. International Energy Agency records show that the greenhouse gas emission from the energy sector will be significantly increased by 130% by 2050 [4]. This rise was highlighted after the introduction of commercial oil-fired thermal power plants.

The year 2020 marked a significant period of loss in energy commodity demand, primarily attributed to the far-reaching impact of the COVID-19 pandemic. The energy sector, like many others, experienced adverse effects as the pandemic caused a decline in the demand for fossil fuels, leading to a drastic collapse in fossil fuel prices. Consequently, the global petroleum industry faced substantial challenges. Lockdown measures enforced for an extended duration resulted in a significant reduction in petroleum fuel imports, leading to a 24.4% contraction in demand compared to the previous year [5]. In 2020, Sri Lanka allocated 24.9% of its non-petroleum export earnings towards fossil fuel imports, leading to a significant reduction in the fuel import bill from USD 4,133 million in 2019 to USD 2,778 million in 2020. This reduction provided some relief to the Sri Lankan petroleum industry. Additionally, the change in government in late 2019 resulted in the discontinuation of the pricing strategies for petroleum products. This change impacted the pricing strategy, burdening the petroleum retail sector. Despite the National Energy Policy and Strategies of Sri Lanka being presented to Parliament in late 2019, its adoption was hindered by limited operations during a significant portion of 2020 [6].

In the field of renewable energy, notable advancements were made in Sri Lanka through the competitive bidding process for solar and wind development programs. These initiatives led to significant achievements, including the commercial operation of eighteen 1 MW solar power plants in 2020. This milestone contributed to a total ground-mounted solar capacity of 75.36 MW [7]. Additionally, the country witnessed the integration of two wind power plants and a waste-to-energy power plant into the grid. The progress of the 100 MW wind power project in Mannar faced initial setbacks due to the pandemic but swiftly recovered, enabling the Ceylon Electricity Board (CEB) to energize several turbines using the existing grid infrastructure [8].

In the energy supply landscape of the country, petroleum maintained its position as the dominant source, accounting for 40% of the energy supply, closely followed by biomass at 34%. The focus on large-scale wind and solar resource development intensified in 2020, alongside the completion of the last three hydropower projects. However, the full utilization of these resources faced delays due to constraints imposed by the country's demand profile. Ongoing studies are being conducted to assess the potential availability of offshore petroleum resources. Coal accounted for 14% of the energy supply, while hydropower contributed 8%, and new renewable energy sources accounted for 4%. The total electricity generation in 2020 amounted to 16,711.3 GWh, with thermal plants contributing 64% of the generation. New renewable energy sources made up 10% of the generation mix. The contribution of micro power producers, specifically solar rooftop systems, reached 3%, while approximately 495.6 GWh of electrical energy was generated through the net-metering, net plus, and net accounting schemes in 2020 [6].

Electricity generation from renewable technologies is being developed in Sri Lanka. In comparison with conventional large power plants, the total electricity production capacity from non-conventional renewable power plants to the national grid is relatively small. To handle this challenging situation some preliminary steps have been taken to generate electricity from renewable energy sources through the installation of wind, solar, and biomass power plants by 2050. The main outcome of these scenarios is to achieve 100% renewable energy. To fulfill this target a Life Cycle Assessment (LCA) is mainly required in three different phases such as construction, operational, and deconstruction. Following a proper LCA facilitates to identify and examine the advantages and limitations of different types of renewable electricity generation sources. This study mainly focuses on the potential for the generation of electricity from wind energy in Sri Lanka and provides an overview of LCA for three life cycle phases of a wind power plant such as construction, operational, and deconstruction.

2 EMISSIONS FROM WIND POWER PLANT LIFE CYCLE PHASES

Emissions can happen during the construction phase of any wind power plant due to some reasons and activities. They can be mentioned as the transportation of construction materials, accessories, equipment, and personnel to the site location which leads to higher combustion of fossil fuels released from vehicles [9]. The usage of construction machinery such as cranes, excavators, and trucks also causes emissions from their internal fuel combustion. The production of cement used in foundations and structures involves the release of carbon dioxide (CO_2) during the calcination process and then it leads to such emissions. Additionally, the manufacturing of wind turbine components, such as blades, towers, and nacelles, can result in emissions from energy-intensive processes, including the processes of material extraction, processing, and fabrication [10]. As same as solar power plants, wind power plants use steel as a major consumable in this phase. Therefore, metal depletion is rapidly increased due to construction activities in wind plants and steel production makes more damage than the damage occurred by the production of aluminum under the metal depletion impact category [11]. When considering the operational phase of wind power plants, it causes emissions mainly due to electricity consumption. The electricity consumed by the wind turbines and associated infrastructure for operation, maintenance, and monitoring can contribute to indirect emissions, depending on the energy mix of the grid supplying the electricity. Regular maintenance activities and inspections of the wind turbines and associated equipment may involve the use of vehicles and machinery, which can generate emissions. As well as due to transmission and distribution losses emissions may occur. During the transmission and distribution of the electricity generated by the wind plant, energy losses in the power grid. Finally, the deconstruction stage is the end-of-life phase, decommissioning and removal of wind turbines and associated infrastructure involve transportation and machinery operations, which can contribute to emissions. Additionally, proper disposal or recycling of decommissioned wind turbine components may incur emissions if not managed effectively.

Management of emissions occurring in these three stages is very important. For that, priority should be given to the factors affected by emissions. This article discusses the factors that contributed to emissions in three life cycle stages (Table 01). When focusing on the construction phase, several factors need to be considered in this stage of a wind power plant to ensure its successful implementation and optimal performance. These factors include site selection, wind resource assessment, turbine selection, and environmental impact assessment. First and foremost, choosing the right location is crucial for maximizing wind resource availability. Factors such as wind speed, wind direction, topography, and proximity to the power grid need to be assessed to determine the site's suitability for wind power generation. At present, higher wind potential areas in Sri Lanka are analyzed to construct effective wind power plants. After the selection of a proper site, conducting a thorough wind resource assessment is essential to accurately estimate the wind potential at the selected site. This assessment involves collecting wind data through meteorological measurements or using historical wind data from nearby locations. By considering some specific factors including turbine size, rotor diameter, hub height, and power output, the selection of the appropriate wind turbine technology and capacity is crucial as it entirely depends on the site-specific wind conditions, power generation requirements, and project budget [12]. The next point is assessing the potential environmental impacts of the wind power plant. This is the most important to comply with regulatory requirements and minimize ecological and social consequences [13]. As the environmental factors, bird migration patterns, noise levels, visual impacts, and habitat preservation need to be evaluated individually [14],[15],[16],[17]. Ensuring a reliable and efficient connection to the power grid is essential for transmitting the generated electricity. Grid infrastructure assessments and coordination with grid operators are necessary to determine the technical requirements and connection feasibility. Adequate infrastructure, including access roads, foundations, and transmission lines, must be planned and constructed to support the installation and maintenance of wind turbines. Considerations for transportation logistics, crane access, and maintenance facilities are important. Compliance with local regulations, permits, and approvals is also vital. This includes obtaining necessary environmental permits, land-use permits, construction permits, and grid connection agreements. Implementation of robust safety protocols during construction is crucial to protect workers and minimize workplace risks. This includes adherence to occupational health and safety standards, training programs, and proper installation practices. Then priority should be given to the project timeline and budget as efficient project management, including scheduling, budgeting, and resource allocation, is essential to ensure timely completion and cost-effective construction of the wind power plant. Additionally engaging and communicating with local communities, landowners, government agencies, and other stakeholders is essential to address concerns, gain support, and foster positive relationships throughout the construction process.

The second one is the operational phase. Generally, routine maintenance activities involve keeping the wind turbines operating at their optimal performance levels. Factors to consider include blade inspection and repair, lubrication of mechanical components, electrical system checking, and monitoring of turbine health through condition monitoring systems. Continuous monitoring of the wind turbines' performance helps identify any deviations or issues promptly [9]. Factors to consider include monitoring power output, wind speed and direction, turbine vibrations, and overall system efficiency. This data helps in identifying maintenance needs, troubleshooting, and maximizing energy production. Then, ensuring a stable and reliable connection to the power grid is essential. Factors to consider include complying with grid code requirements, monitoring grid integration, and maintaining a power purchase agreement with the grid operator or utility company. Implementation of remote monitoring and control systems allows for real-time monitoring of turbine performance and immediate response to any operational issues. This includes monitoring wind conditions, power output, and system health, as well as adjusting turbine settings remotely if needed [18]. As same as the construction phase, monitoring and mitigating the environmental impact of the wind power plant during the operational phase is important. Data analysis and performance optimization is a considerable factor as analyzing operational data collected from the wind turbines helps identify patterns, trends, and areas for improvement [19]. Factors to be considered include data analysis for optimizing energy production, reducing downtime, and implementing predictive maintenance strategies. Implementing comprehensive safety protocols and emergency response plans is essential to protect personnel, prevent accidents, and respond effectively to any emergencies. Regular safety training, equipment maintenance, and emergency drills should be conducted. Lifecycle assessment and sustainability is the key factor because assessing the lifecycle environmental impact and implementing sustainable practices in operations, such as recycling and waste management, helps minimize the overall environmental footprint of the wind power plant.

The final life cycle phase of a wind turbine is the deconstruction phase. Initially, there is a proper plan available for deconstruction. Developing a comprehensive decommissioning plan is essential to guide the deconstruction process. The plan should outline all the necessary steps, timelines, and responsibilities for dismantling and removing the wind turbines and associated infrastructure. Regulatory Compliance is also required as it ensures compliance with local regulations and permits for decommissioning is necessary. This includes obtaining the necessary permits, notifying relevant authorities, and following any specific requirements for the disposal or recycling of materials. Proper waste management practices should be followed as the management of waste generated during this process is important for environmental protection. Proper sorting, recycling, and disposal of materials, such as metals, concrete, fiberglass, and electronic components, should be carried out according to local regulations and best practices [9]. Site remediation is restoring the site to its pre-construction condition or repurposing it for other uses may be necessary. This may involve activities such as removing concrete foundations, reclaiming disturbed land, and addressing any potential environmental contamination. As well as material recycling and reuse is a compulsory step since maximizing the recycling and reuse of decommissioned wind turbine components helps reduce waste and resource consumption. Identifying opportunities for recycling metals, repurposing components, or using them in other industries should be explored. Proper financial planning and budgeting for the deconstruction phase is crucial. Anticipating the costs associated with equipment, labor, waste management, and site remediation ensures a smooth and financially viable decommissioning process. As an effective stakeholder communication method, maintaining open and transparent communication with local communities, landowners, and stakeholders is important during the deconstruction phase. Addressing concerns, providing updates, and involving stakeholders in decision-making processes help foster trust and understanding. Finally, documentation and reporting are essential as documenting the deconstruction process, including waste management records, recycling efforts, and any environmental assessments, is important for accountability and regulatory compliance. Reporting on the decommissioning activities may be required by local authorities or industry standards.

Table 1: Factors affected to three life cycle phases of a wind power plant

Construction Phase	Operational Phase	Deconstruction Phase
1. Site Selection	1. Routine Maintenance	1. Decommissioning Plan
2. Wind Resource Assessment	2. Performance Monitoring	2. Regulatory Compliance
3. Turbine Selection	3. Grid Connection and Power Purchase Agreements	3. Health and Safety
4. Environmental Impact Assessment	4. Remote Monitoring and Control Systems	4. Component Removal
5. Grid Connection	5. Environmental Monitoring	5. Waste Management
6. Infrastructure and Access	6. Data Analysis and Performance Optimization	6. Site Remediation
7. Permitting and Regulatory Compliance	7. Safety and Emergency Response	7. Material Recycling and Reuse
8. Safety Measures	8. Community Engagement and Stakeholder Communication	8. Financial Planning
9. Project Timeline and Budget	9. Regulatory Compliance	9. Stakeholder Communication
10. Stakeholder Engagement	10. Lifecycle Assessment and Sustainability	10. Documentation and Reporting

3. FUTURE DIRECTIONS FOR REDUCING EMISSIONS FROM CONSTRUCTION, OPERATIONAL, AND DECONSTRUCTION PHASES

Reducing emissions in the construction, operational, and deconstruction phases of wind power plants is crucial for minimizing the environmental impact of renewable energy projects. Here are some solutions to help mitigate emissions throughout these phases:

1. Construction Phase:

- Efficient Transportation Usage: Optimization of logistics and transportation routes to reduce fuel consumption and emissions during the delivery of construction materials and equipment.
- Following Green Construction Practices: It’s necessary to promote sustainable construction methods, such as using locally sourced materials, employing energy-efficient machinery, and adopting environmentally friendly construction techniques.
- Renewable Energy Usage: Power construction activities with renewable energy sources whenever possible to minimize reliance on fossil fuels.

2. Operational Phase:

- Renewable Energy Consumption: Ensure that the energy consumed by the wind power plant's operations is sourced from renewable sources to minimize indirect emissions.
- Regular Maintenance: Implement proactive maintenance programs to optimize turbine performance, ensuring efficient operation and reducing energy losses.
- Energy Storage: Install energy storage systems to balance power supply and demand, maximizing the utilization of renewable energy and reducing reliance on backup power sources.

3. Deconstruction and End-of-Life Phase:

- Recycling and Reuse: Develop strategies for the proper recycling and reuse of decommissioned wind turbine components, minimizing waste and emissions associated with disposal.
- Sustainable Decommissioning: Implement environmentally responsible decommissioning processes that prioritize the recycling and proper disposal of materials while minimizing emissions from machinery and transportation.
- Circular Economy Approach: Promote the adoption of circular economy principles by designing wind turbines and their components for easier disassembly, recycling, and reuse.

4. Lifecycle Assessment and Carbon Offsetting: Conduct thorough lifecycle assessments to identify emissions hotspots and implement targeted mitigation measures. Consider carbon offsetting programs to compensate for unavoidable emissions by investing in renewable energy projects or carbon sequestration initiatives.
5. Collaboration and Knowledge Sharing: Foster collaboration between industry stakeholders, governments, and research institutions to exchange best practices, technological advancements, and innovations for emissions reduction in wind power plant lifecycle phases.

Implementing these solutions requires the collaboration of project developers, contractors, operators, and policymakers. By prioritizing emissions reduction and sustainability throughout the lifecycle of wind power plants, the industry can make significant strides toward achieving cleaner and more sustainable energy generation.

4. CONCLUSION

The global electricity generation mix continues to be dominated by conventional fossil fuels, resulting in significant environmental consequences such as greenhouse gas emissions, air pollution, and ecological degradation. However, there is a growing recognition of the need to transition to sustainable alternative energy sources to address these challenges and meet the increasing global energy demand. Renewable energies, including hydroelectric, wind, and solar power, offer promising solutions to reduce the environmental impact associated with electricity production. Sri Lanka, as a developing country, has experienced a transformation in its electricity generation mix. The country has made some notable advancements in the development of renewable energy sources, such as solar and wind power plants, as a major part of its efforts to achieve a more sustainable and renewable energy future.

While the construction, operational, and deconstruction phases of wind power plants contribute to emissions, several factors can be considered to mitigate their environmental impact. To further reduce emissions throughout the lifecycle of wind power plants, additional measures can be taken, including the adoption of carbon offsetting programs, collaboration between industry stakeholders and research institutions, and the promotion of a circular economy approach. By implementing these solutions and prioritizing sustainability, the wind power industry can make significant strides in reducing emissions and achieving cleaner and more sustainable energy generation. These efforts align with global goals of mitigating climate change, reducing dependence on fossil fuels, and creating a more sustainable future for generations to come. Continued investment, innovation, and collaboration will be crucial in driving the transition towards a renewable energy-based electricity generation mix.

5. REFERENCES

[1] (International Energy Agency) IEA, “Key World Energy Statistics 2020,” *Int. Energy Agency*, vol. 33, no. August, p. 4649, 2020, [Online]. Available: https://www.iea.org/reports/key-world-energy-statistics-2020.

[2] S. Jaber, “Environmental Impacts of Wind Energy,” *J. Clean Energy Technol.*, vol. 1, no. 3, pp. 251–254, 2014, doi: 10.7763/jocet.2013.v1.57.

[3] D. Y. C. Leung and Y. Yang, “Wind energy development and its environmental impact: A review,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 1031–1039, 2012, doi: 10.1016/j.rser.2011.09.024.

[4] M. R. Islam, S. Mekhilef, and R. Saidur, “Progress and recent trends of wind energy technology,” *Renew. Sustain. Energy Rev.*, vol. 21, pp. 456–468, 2013, doi: 10.1016/j.rser.2013.01.007.

[5] O. Faruk, A. K. Bledzki, H. P. Fink, and M. Sain, “Biocomposites reinforced with natural fibers:

2000-2010," *Prog. Polym. Sci.*, vol. 37, no. 11, pp. 1552–1596, 2012, doi: 10.1016/j.progpolymsci.2012.04.003.

[6] Eurostat, "Energy Balance 2020," pp. 1–238, 2020.

[7] M. Danthurebandara and L. Rajapaksha, "Environmental consequences of different electricity generation mixes in Sri Lanka by 2050," *J. Clean. Prod.*, vol. 210, pp. 432–444, 2019, doi: 10.1016/j.jclepro.2018.10.343.

[8] S. Sritharan and B. Cai, "Onshore Wind Energy Potential in Sri lanka," *Int. Conf. Eng.*, pp. 17–21, 2022.

[9] S. Wang and S. Wang, "Impacts of wind energy on environment: A review," *Renew. Sustain. Energy Rev.*, vol. 49, no. 2015, pp. 437–443, 2015, doi: 10.1016/j.rser.2015.04.137.

[10] C. L. Archer *et al.*, "Review and evaluation of wake loss models for wind energy applications," *Appl. Energy*, vol. 226, no. February 2018, pp. 1187–1207, 2018, doi: 10.1016/j.apenergy.2018.05.085.

[11] K. Treyer and C. Bauer, "Life cycle inventories of electricity generation and power supply in version 3 of the ecoinvent database—part II: electricity markets," *Int. J. Life Cycle Assess.*, vol. 21, no. 9, pp. 1255–1268, 2016, doi: 10.1007/s11367-013-0694-x.

[12] E. Muljadi, C. P. Sandy Butterfield, and M. L. Buhl, "Effects of turbulence on power generation for variable-speed wind turbines," *35th Aerosp. Sci. Meet. Exhib.*, no. January, 1997, doi: 10.2514/6.1997-963.

[13] R. R. Reviews *et al.*, "Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses," *Front. Ecol. Environ.*, vol. 5, no. 6, pp. 315–324, 2007, [Online]. Available: http://www.esajournals.org/doi/abs/10.1890/1540-9295(2007)5[315:EIOWED]2.0.CO;2.

[14] E. Pedersen and K. Persson Waye, "Perception and annoyance due to wind turbine noise—a dose–response relationship," *J. Acoust. Soc. Am.*, vol. 116, no. 6, pp. 3460–3470, 2004, doi: 10.1121/1.1815091.

[15] K. Dai, A. Bergot, C. Liang, W. N. Xiang, and Z. Huang, "Environmental issues associated with wind energy - A review," *Renew. Energy*, vol. 75, pp. 911–921, 2015, doi: 10.1016/j.renene.2014.10.074.

[16] M. S. Nazir, N. Ali, M. Bilal, and H. M. N. Iqbal, "Potential environmental impacts of wind energy development: A global perspective," *Curr. Opin. Environ. Sci. Heal.*, vol. 13, pp. 85–90, 2020, doi: 10.1016/j.coesh.2020.01.002.

[17] J. K. Kaldellis, K. Garakis, and M. Kapsali, “Noise impact assessment on the basis of onsite acoustic noise immission measurements for a representative wind farm,” *Renew. Energy*, vol. 41, pp. 306–314, 2012, doi: 10.1016/j.renene.2011.11.009.

[18] J. K. Kaldellis and D. Zafirakis, “The wind energy (r)evolution: A short review of a long history,” *Renew. Energy*, vol. 36, no. 7, pp. 1887–1901, 2011, doi: 10.1016/j.renene.2011.01.002.

[19] E. Martínez, E. Jiménez, J. Blanco, and F. Sanz, “LCA sensitivity analysis of a multi-megawatt wind turbine,” *Appl. Energy*, vol. 87, no. 7, pp. 2293–2303, 2010, doi: 10.1016/j.apenergy.2009.11.025.