Renewable Energy Based Smart Microgrids—A Pathway To Green Port Development

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ABSTRACT

Ports as an industry account for 3% of global greenhouse gas emissions. Sustainable initiatives and zero net energy goals are driving the use of renewable energy sources, such as solar photovoltaic, wind, and other systems. The main objective of this article is to discuss ways to reduce greenhouse gas emissions inside the port by integrating renewable energy technologies in an efficient manner using micro grids. Clean energy-based, direct current (DC) microgrids are considered as a revolutionary power solution. In several development sectors, they are becoming increasingly attractive to researchers since they generate less greenhouse gases (GHGs), lower operating costs, and offer flexibility. This article highlights and details the benefits of implementing renewable-based DC microgrids with suitable energy storage technologies to achieve sustainable port energy management.

INTRODUCTION

Global shipping is normally powered by standalone diesel generators that supply electricity. Shipping and port facilities are affected considerably by the cost of electricity generation. The use of renewable energy (RE) resources in the shipping industry would be advantageous, particularly in reducing CO_2 emissions and reducing dependence on fossil fuels. However, the intermittency associated with RE utilization and recent large increases in its share of total power generation can result in problems with power generation, distribution and demand, creating potential for grid instability. The magnitude of these problems can be reduced by developing large numbers of microgrids with energy storage capabilities. Microgrids are small electricity grids that can operate independently or be connected to larger utility grids. These could have individual capability to manage supply and demand if these microgrids were integrated with the primary electrical grids. Then smart microgrids would enable consumers to connect to the primary energy delivery networks.

Several researches are developing on-board, renewable-based microgrid systems for maritime applications. Corredor et al. developed a novel hybrid propulsion system of an internal combustion engine (ICE) coupled with an electric motor powered by batteries through an electric DC bus device in a parallel configuration system increasing a boat's travelled distance to fuel consumption ratio [1]. Parameters including boat size and engine hybrid configuration were simulated. Strunz et al. proposed a DC microgrid with RE systems [2]. Further, a new method to quantify the uncertainties affiliated with the forecast of aggregated wind and photovoltaic (PV)-based power generation was developed and used to quantify the reserve of its battery energy storage system. Microgrid systems can operate in autonomous mode, supporting an uninterruptable power supply (UPS) when connections to the main grid are unavailable. Jayant Kumar discussed the importance of developing smart microgrids in port owned applications [3]. A new microgrid system has been suggested for Philadelphia Navy Yard Alstom. Krkoleva et al. developed a pilot microgrid for a rural location [4]. Their microgrid encompassed a part of a farm's existing low voltage grid and included sample loads plus a generator. Electrical loads within the microgrid could be supplied either by the grid or by electricity produced by renewable sources.

Cherry et al. stated that there is a strong correlation between electrification and rising human development, but in developing countries access to electricity is often unreliable, unavailable, or unobtainable, especially from a centralized electric grid [5]. They developed the concept of using a biogas digester to supply an internal combustion engine with fuel to generate electricity for portable energy storage devices (PESDs) for decentralized electrification. Hebener et al. examined the aspects of terrestrial microgrids and ship power systems [6]. They stated that the balancing strategy is an effective tool to improve system-level stability on finite inertia power systems, an important consideration in early-stage microgrid and ship power system designs. Gerry et al. optimized distributed energy resources (DER) that included distribution generation (solar PV array, wind energy, hydro and biogas fueled generators) with battery backup [7]. They adopted an approach based on mathematical modelling for each component of DERs with optimization carried out using HOMER (a software tool) to determine the economic feasibility of DERs to ensure reliable power supply to load demand and minimize cost. The methodology for overcoming several technical challenges in RE systems for isolated applications was also discussed. Mariam et al. performed a technology and economic analysis of micro generation for the development of community based microgrid systems [8]. They performed this analysis for wind power supplied micro generation systems for communities that lacked RE feed-in-tariff policies.

This article next considers the integration of renewable based power generation and introduces the concept of a smart microgrid for the Port of Chennai, India. This study is useful to analyze the feasibility of RE deployment within the community context while minimizing environmental pollution. The proposed DC microgrid is a model for the development of greener ports and their facilities.

ENERGY CONSUMPTION PATTERN AT THE PORT OF CHENNAI

The Port of Chennai, formerly known as Madras Port, is the fourth largest port in India in terms of throughput. It is situated on the Coramandel coast and has a handling capacity of 86 million tonnes (Mt) annually. The port has 24 berths for cargo handling, distributed along three docks and has an entrance channel of seven kilometres in length. The port's electricity is provided by the Tamil Nadu Generation and Distribution Corporation (TANGEDCO).

The port uses enormous amounts of electricity and diesel for the intermodal transportation of goods and for providing essential services. It uses diesel fuel for trucks, generators, rail locomotives, cranes and mooring launches. The diesel operated cranes are located in container terminals 1 and 2. The port has five tug boats for maneuvering merchant vessels to berth, two dredgers for maintaining the depth of the quay, four mooring launches, 8 Nos. of 700 HP Locos (railway locomotives) and 2 Nos. of 1,400 HP Locos. The transmission of power to the locos makes use of an alternator. The diesel consumption by port-owned vehicles, cranes operated at container terminals 1, 2, and other equipment total 6.3 million litres annually. Of this total, 59.2 % of the diesel consumption is used by cranes, 25.5% by tug boats and 15.3% by other equipment. The diesel consumption by the port's vehicles and equipment are illustrated in Figure 1.

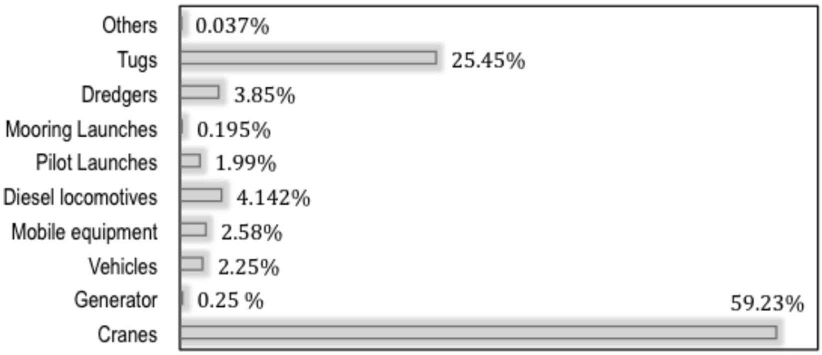

Figure 1. Diesel consumption by various port-owned vehicles and equipment.

The major electrical energy consumers in the Port of Chennai include: 1) port owned equipment like cranes, pumps, reefer (refrigerated vessels) containers; 2) private operated cranes for container movement, transfer cranes for intermodal transportation of containers; and 3) the housing colony. The electrical energy consumers in the Port of Chennai are shown in Figure 2.

At the port, electrical energy is used for lighting, air conditioning for buildings, and to power cargo handling equipment. Electric cranes, located on the quays, are used mainly for handling dry bulk cargo and occasionally for dredging along berths to salvage cargo that has slipped or spilled along the berth during handling. The total electricity consumption of the Port of Chennai includes port owned equipment, port tenants, user operated equipment, and the electrical energy consumed by the housing colony. The total electrical usage is 25.0 GWh per year and is allocated as shown in Table 1. The electricity consumption by the port owned equipment is 5.65 GWh/year (22.6%) of the total electrical energy consumption). The energy consumption by the port tenants and users due to operation of cranes for container movement and transfer cranes for intermodal transportation of containers in container terminals 1 and 2 accounted for 16.55 GWh/year. The electrical energy consumed in the housing colony due to lighting,

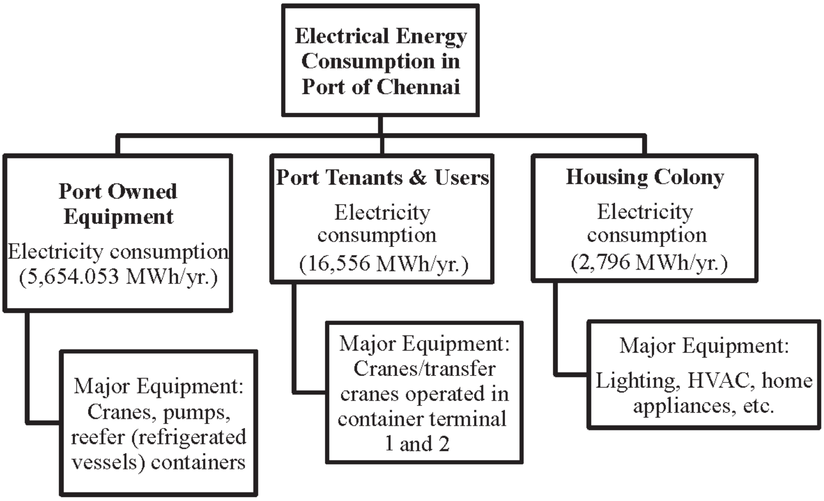

Figure 2. Major electrical energy consumers at Port of Chennai.

air conditioning loads and other home appliances accounted for 2.8 GWh annually.

Table 1. Major electrical consumption equipment/utilities at the Port of Chennai.

Equipment	Electrical consumption (MWh/yr.)
Port owned motors for crane operation	2,092
Port owned pumps	2,035
Port owned lighting, HVAC & other loads	1,527
Container terminal 1	8,297
Container terminal 2	6,511
Other port users	1,748
Housing colony	2,796
Total	25,006

RENEWABLE ENERGY TECHNOLGIES FOR PORT ACTIVITES

The process of developing a strategic plan to match the proposed renewable power generation for a port's electricity demand involves technical, organizational and port policy analysis. This process involves fully integrating the port within the host community to achieve the goal of being a "Green Port." Options for the Chennai Port include harnessing sea breezes to generate electricity by installaing wind turbines, generating power using solar PV systems, and producinig biogas from fishing harbour wastes. Electricity produced from these RE resources would support the development of a smart microgrid, using the electricity efficiently for various on-site applications. Next we consider proposed power generation from renewable energy sources.

Power Generation Using Solar PV

India is endowed with rich solar energy resources due to its location in the Earth's equatorial areas. The daily average solar energy incidence in India varies from 4 to 7 kWh/m^2 and is roughly 5.6 kWh/m^2 in Chennai. There are about 300 clear and sunny days in a typical year. The capacity utilization factor (CUF), as evaluated by Equation 1 is 19% in Tamil Nadu. For example, a 1 kWp solar installation would be able to generate about 4.56 units (4.56 kWh) of electricity daily.

$$CUF = Actual\ energy\ from\ the\ plant \div \left(Plant\ capacity\ \left(kW_p\right) \times 24 \times 365\right) \quad (1)$$

The average potential roof area requirement for a typical 1 kWp solar PV power plant will be approximately 9.5 m^2 of shade-free area. Port of Chennai, with a roof-top area (warehouse, transit shed, administrative blocks and housing colony) of 82,142 m^2, would be able to develop a 8.65 MW solar PV power plant, generating close to 14.4 million units (14.4 GWh) of electricity per annum. This clean source of electrical energy would reduce GHG emissions by 16,262 tonnes annually. Jurong Port, Singapore [1,5] announced its installation of solar panels in more than 95,000 square meters of warehouse roof space, which it claims would make it the largest port-based solar facility in the world. Port of Chennai is considering the installation of solar PV systems using the rooftop space available on buildings. A minimum of 5 MW is recommended for the installation, which would generate 8.32 million units (8.32 GWh) of electricity annually.

Wind Energy

Among the types of renewable energy sources available, power generation by wind energy is the most cost effective, and the cost of generating electricity is comparable with other conventional sources. Tamil Nadu, the southern state in India where the Port of Chennai is located, has three prominent passes with high wind potentials during the monsoon season. Installing wind turbines generators (WTGs) at the port can capture the wind energy from coastal breezes to drive the generators and produce electric power. WTGs produce electricity that is delivered to batteries and loads in the fishing boats using an AC to DC converter and a battery charger. Offshore wind development in particular is an ideal way for modern green ports to increase revenue and gain a competitive advantage.

Port of Chennai plans to develop offshore wind energy for the following reasons:

- Wind energy is abundant and available.
- WTGs occupy minimum space.
- Being environmentally neutral, it complies with air emission regulations.
- Modern wind energy technology is closely associated with port technology and operations.
- Ports are an ideal location for both land-based and offshore farms.
- From financial and commercial standpoint, ports are ideal consumers of renewable energy, which is compatible with maritime and port energy generating technologies.

Continuing its efforts towards its green port initiative, Chennai port trust has proposed development of a wind farm with an initial capacity of 6.5 MW. Total annual net energy generation from the wind farm will be about 14.6 million units (14.6 GWh), which will account for about 58% of the port's annual electrical energy requirements.

Energy Generation Using Fishing Harbour Waste

The Port of Chennai intends to identify the potential for biogas production from fishery wastes. Fish waste was determined to be a potential substrate for biogas production. It has great potential as a source of highly valued organic carbon for methane production.

The energy content of biogas is directly related to methane concentrations. Biogas production from fish waste is about 1,279 m^3 per tonne of total solids (TS). Biogas produced using fish waste has high methane concentrations, about 71%. A typical normal cubic meter of methane has a calorific value of around 10 kWh, while carbon dioxide has zero. In the case of biogas produced from fish waste, the calorific value is 7.1 kWh/ Nm^3. This biogas can be used as a fuel in stationary engines with 30% to 40% of the energy used to produce electricity while the remaining energy becomes heat.

The fishing harbour managed by the Port of Chennai generates a large volume of fish waste (1,200-1,300 tonnes annually). This waste is disposed by the corporation of Chennai. Using a 30% conversion efficiency, the Port of Chennai could generate 3.8 million kWh of electricity per annum with the accumulated fish wastes, producing nearly 15% of the total electricity needed by the Port of Chennai. To enhance the conversion efficiency from the biogas, combined heat and power generation is proposed as shown in Figure 3. The heat generated can be utilized to generate potable water with a multi-effect evaporator, meeting the port's entire potable water requirements.

Considering the benefits depicted in the Figure 3 scenario, the port is proposing the installation of a biogas power system with two biogas generators (200 kW and 300 kW) to reduce the potential of part load operation. This system would generate 3.5 GWh of electricity annually.

Microgrid Using Renewables With Energy Storage

Sustainable renewable energy can be provided with a DC microgrid to minimize the energy needed to operate cranes and other equipment at the Port of Chennai. Most renewable energy resources generate direct current electricity. Microgrids are decentralized electric grids that combine clusters of loads and parallel distributed generation systems in a local area. Local DC microgrids are being used for data and telecommunications centres. There is a potentially large market for DC microgrids in the developing world. The benefits they offer to the world's underserved regions continue to grow as RE power generation in developing countries increases. Distributed RE based DC microgrids can reduce distribution and transmission requirements. Other advantages of DC microgrids support consumer needs, local utilities and their communities. These include enhanced power performance, reduced overall power consumption, lowered greenhouse gases and pollutant emissions, increased service quality and local reliability.

There is a growing realization that energy storage (ES) systems will be key technologies in future electricity transmission networks, particularly those with heavy dependence on RE resources. Energy storage systems can: 1) enable a match between supply and demand; 2) replace

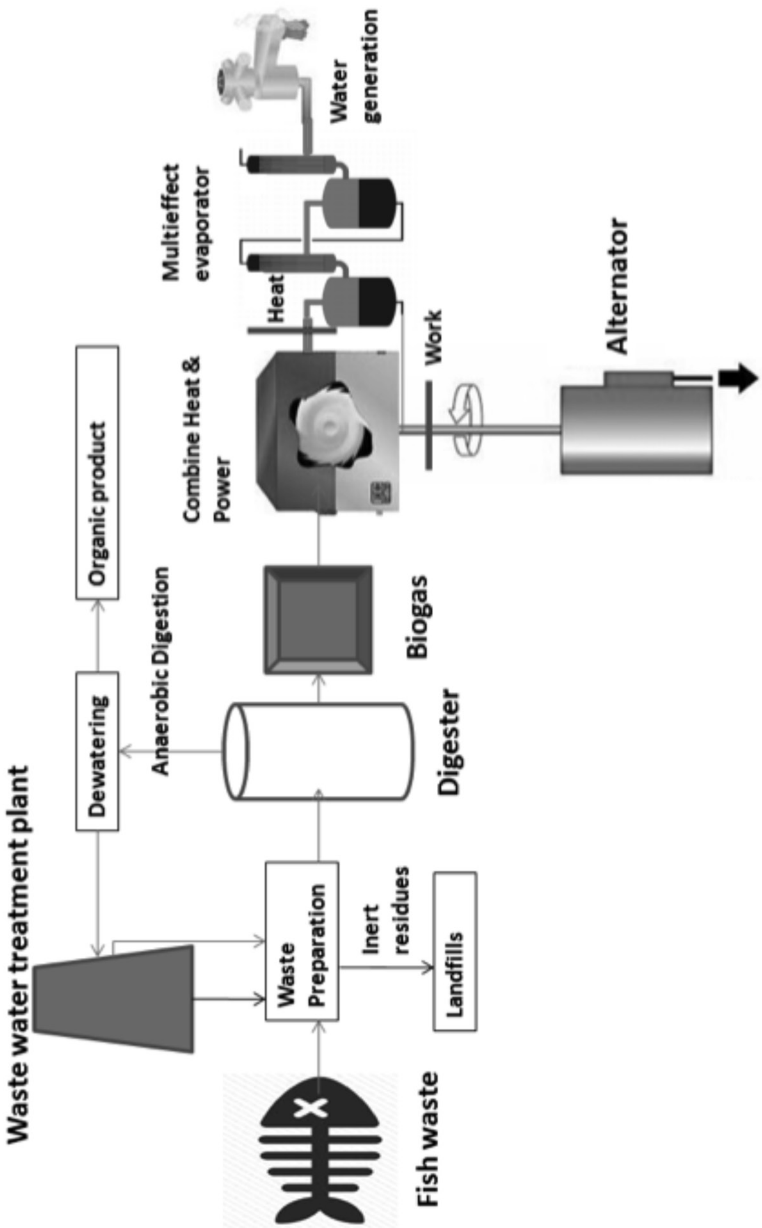

Figure 3. Biogas generation and utilization from fishing harbour waste.

inefficient auxiliary power production; 3) ensure grid stability with a diversified energy supply and increased levels of renewable penetration; 4) ensure security of supply; and 5) facilitate distributed generation. A diverse range of electrical and thermal energy storage technologies exist, differentiated by power and energy density, physical size, cost, charge and discharge time periods and market readiness. For medium- to large-scale electrical storage requirements involving timescales in hours, mechanical and electrochemical ES technologies are the most viable, but no one technology can fulfill all of the required roles. The energy storage technologies being developed include advanced batteries, compressed air energy storage, fuel cells and others to store intermittent renewable energy resources. Integrating energy storage technologies into generation and distribution networks requires an understanding of the potential benefits and risks, conformity with network operation rules, the optimal mix of thermal and electrical storage to achieve the multiple objectives of CO_2 reductions, cost minimization, safety and reliability.

Demonstrating the use of electric mobility in ports and port owned areas is increasingly important. Electric boats are more efficient than boats with diesel engines. A 100% clean energy port is achievable if all boats, vehicles and machinery operating in the port used electrical power.

As handling cargo in harbours and ports is typically performed using cranes and vehicles, efforts are underway to make them more environmentally friendly. Most of these types of vehicles are diesel driven but could be equipped with electric battery operated systems. A major portion of the energy used in the Port of Chennai is for operating cranes and heavy machinery. Container cranes that lift and lower containers are the most electrical energy consuming equipment in port terminals. While lifting the container, the current required depends upon the applied torque. While the crane is lowered, it is possible to generate electricity and store it in batteries.

PROPOSED SYSTEM

A ship's power system is a microgrid. It contains generation, distribution and loads. At sea, it is both isolated and self-sufficient. In a similar manner a DC microgrid is proposed for the Port of Chennai (see Figure 4), with power generation from RE sources.

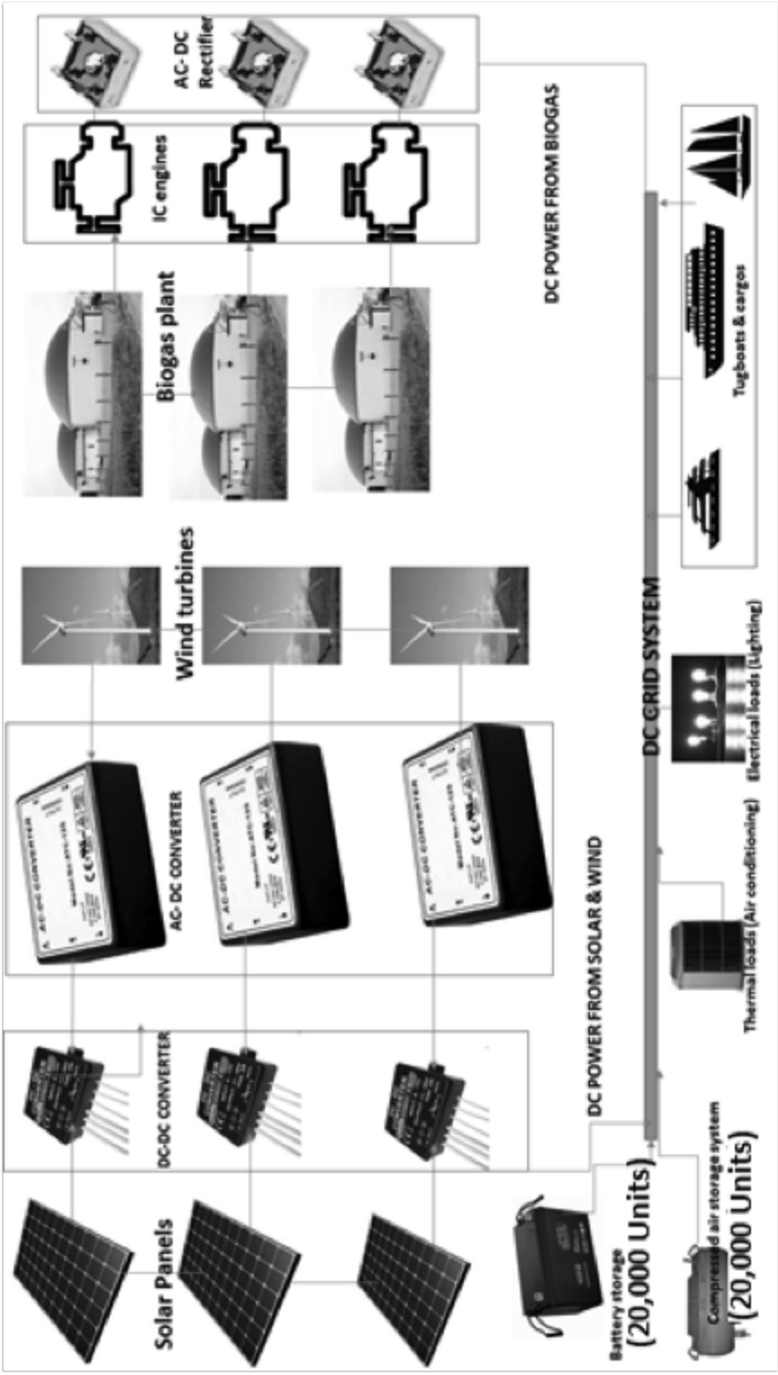

Figure 4. Illustration of proposed renewable energy DC microgrid system.

The port plans to meet its entire electrical energy requirement with RE using a microgrid. The power required for the electrical distribution system is obtainable using a 5 MW solar PV system (8.32 GWh/annum), a 6.5 MW of wind power system (14.6 GWh/annum), and 500 kW of biogas generation (3.5 GWh/annum). The power generated from these systems is fed to the DC microgrid after conditioning the generated electricity with power conditioning equipment. A new DC bus system and transmission lines will be designed and installed based on microgrid requirements.

Energy storage devices, including batteries and super capacitors, are being considered for use by port vehicles and cranes to reduce power fluctuations that result in higher costs and energy consumption. The average daily electricity consumption is about 70,000 kWh. To store approximately 60% of the total daily electricity requirements, a battery storage and compressed air energy storage system will be installed. The battery storage system will be designed to store 20,000 units of electricity and provide a buffering source for electricity to operate cranes and other port owned vehicles. The battery will be sized for a capacity of 72 volt, 630 amp hours to provide a continuous energy supply of 20,000 units of electricity. A new compressed air energy storage system (CAES) is suggested to store nearly 20,000 units of electricity using a 10,000 m^3 storage tank at a pressure of 50 bar. It is also suggested that the stationary cranes and hoists operated in the port be replaced by pneumatic cranes using the stored compressed air from the CAES.

CONCLUSIONS

Generating on-site renewable power at ports can significantly reduce pollution, improve public opinion of the ports, and reduce their energy expenses. The RE technologies suggested in this article are useful in planning effective CO_2 mitigation strategies to incorporate technological advancement and management policies. Microgrids provide an opportunity to allow ports to meet their electrical energy requirements.

An assessment, accounting and estimate of energy consumption from the individual systems for the Port of Chennai, India are offered in this study. The port has the potential to implement renewable energy technologies with energy storage using a microgrid. The suggested direct current microgrid uses solar power, wind turbine generators, and biogas generation to enable the port to provide most of its electrical energy needs. Energy storage systems, including conventional batteries and compressed air, can provide 60% of the port's total daily electricity requirements. The information in this article can assist policy makers to enforce mandatory measures in certain systems, accelerate the growth of environmentally friendly renewable energy and energy storage technologies, and encourage green port development.

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