CHAPTER 2

LITERATURE SURVEY

Carbon footprint serves as the right tool to track the emission trend and to provide information required for the mitigation of GHG emissions associated with ports. Carbon footprint represents the amount of GHG emissions, an individual organization or event directly or indirectly releases over a measured period. The development of a structured GHG inventory helps to identify the areas, where the improvements could be made in order to mitigate GHG emissions and to evaluate the effectiveness of the mitigation measures over a period of time. The current challenges for the marine and port related industry are to develop environmentally sound, cost-effective concepts and practical solutions to achieve near-zero emission technologies. The present work focuses on data evaluation, energy accounting, developing GHG emission inventories at port of Chennai and exploring the potential of various renewable energy resources in mitigating the carbon footprints. Hence, a detailed literature review has been made on international standards/guidelines pertaining to energy accounting, carbon footprint mitigation and renewable energy utilization for various port activities and a DC microgrids.

2.1 CASE STUDIES OF INTERNATIONAL PORTS

Several studies have been carried out in the past on estimating the GHG emissions for the seaport activities. The major sources of air pollution at
ports and their impact on health were extensively studied by Bailey and Solomon (2004). They suggested a broad range of mitigation approaches such as switching to cleaner versions of diesel fuel, restricting truck idling hours, transitioning to alternative fuels, replacement of older diesel equipment. They also proposed measures that incorporate emerging technologies like shore-side power for docked ships, zero emission technologies such as fuel cells and automated container handling. After the extensive environmental analysis of a port, a system of 21 sustainable environmental management indicators was proposed by Peris-Mora et al.(2005) to be used by port authorities.

Schrooten et al.(2008) studied the effect of recent international efforts to reduce the emissions from sea going vessels. Their investigations revealed that CO$_2$e emissions were likely to increase by 2 to 9% between 2004 and 2010, NOx emissions by 1 to 8% and SOx emissions would decrease by 50%. Wang et al.(2008) compared global ship emission inventories using automated mutual-assistance vessel rescue data set and stated that the world cargo fleet accounted for about 80% of world commercial fleet emissions. They also generated spatial proxies of global ship traffic, and they used two global ship reporting data as proxies to geographically resolve global ship emissions. Meyer et al.(2008) estimated the atmospheric emissions by international merchant shipping in the Belgian part of the North Sea, including the four Belgian seaports and compared their results with international emission estimates. The emissions were estimated based on the bottom up, activity-based methodology. Their results revealed that a total of 1880 kton of CO$_2$, 31 kton of SO$_2$ and 39 kton of NO$_x$ was the emissions from the port for the period between 2003 and 2004.

Han (2010) presented a review article that focused mainly on the status of pollution mitigation measures implemented in the shipping sector. (i) The major sources of air pollution in the shipping industry, (ii) emissions from
ocean-going vessels, international measures against air pollution from ships and emission mitigation strategies in the shipping industry are discussed and critically reviewed in their article. In addition, the authors developed an environmental evaluation scheme by investigating the actual conditions of environmental pollution from ship / port area. GHG emissions from the Port of Barcelona, the biggest Spanish port was estimated by Villalbaet al.(2011). The authors reported that the port handled a total of 2,074, 554 tonnes of cargo and resulted in ~ 53% of total GHG emissions.

The total GHG emissions were accounted to be 331,390 tonnes in 2008, half of which were attributed to vessel movement (sea-based emissions) and the other half to port- land related activities (land-based emissions). They also reported that the biggest polluters were auto carriers with 6 kg of GHG emissions per ton of cargo handled. The main limitation of their study is that the emissions due to industrial process that is carried out inside the port were not considered. Fitzgerald et al. (2011) used a cargo based methodology and estimated that the international maritime transport of New Zealand’s import and export consumed 2.5 million tonnes of fuel during the year 2007, which generated 7.7 Mt of CO$_2$e emissions, 180 kton of NO$_x$, 110 kton of SO$_2$ and 740 ton of CH$_4$. Their study presented the method of estimating the international maritime emissions for individual countries, based on the country’s imported and exported goods. Liao et al. (2010) investigated the variations in carbon dioxide emissions resulting from the movement of containers from established ports through the emerging port of Taipei in Northern Taiwan.

The activity-based emission model is adapted to estimate CO$_2$ emissions. In addition to the existing three ports at Taiwan, the port of Taipei is the newly built port under BOT basis. The authors suggested that if 30% of the containers change their port of call from three existing ports to the port of
Taipei, ~20% reduction in CO₂ emissions is expected in terms of export/import of containers. They suggested the adoption of an analytical approach to understand the prospective CO₂e emission reduction in the route selection of inland container transportation.

Gibbs et al. (2014) analyzed the secondary data and information on action taken by UK ports to reduce their emissions. Centered on their studies of operations at five major UK ports, they reported that emissions from shipping at berth were ten times greater than those from the ports own operations. Moreover, it was seen that shipping emissions associated with seaborne trade at those ports were more important than the ones generated by port operations. An addition information about the CO₂ emissions (548,075 tonnes) for the year 2008 from all UK ports was projected in the study. Chang et al. (2013) measured the greenhouse emissions, particularly from ocean going vessels in the Port of Incheon. The GHG emissions were calculated based on the type and movement of a vessel from the time of its arrival to its docking, cargo handling, and departure. Their results revealed that out of the total CO₂ emissions (370,000 tonnes) estimated, vessels transportation and maneuvering the ships to docks accounted for 96% of the total CO₂ emissions.

2.2 RENEWABLE ENERGY UTILIZATION FOR VARIOUS PORT ACTIVITIES

Global shipping is normally powered by standalone diesel generators for electricity supply and hence the shipping and ports are affected considerably by the cost of electricity generation. Therefore, the use of renewable energy resource in the shipping industry would be a great advantage to reduce the dependence on the fossil fuels. In this section, literature survey pertaining to utilization of renewable energy resources on
different aspects for various port activities was made. In the port of Chennai, electricity and diesel are the major source of fuels for the operation of robust cranes and boat engines respectively for various operations. Power generation through various renewable energy resources and use of bio-diesel in diesel engines could be a sustainable solution in terms of both smart energy management and CO$_2$ mitigation. Realizing this, the Ministry of Shipping, Government of India has recently introduced an incentive scheme under which the ministry will share up to 50% of the total project cost that promote the use of Green energy sources such as solar, wind, biogas and the use of biodiesel. Hence the major Indian ports are now keen in analyzing the feasibility of implementing the green initiatives. This study is also towards analyzing the feasibility of utilizing the renewable sources in an efficient manner at Port of Chennai, India.

The concepts of “Green Shipping” or “Sustainable Shipping” are now becoming important in shipping sector globally. Holland et al. (2014) from their analysis identified five policy areas to link the local need with the global disclosure and addressed the promotion of renewable, low-carbon maritime operations. Gilbert et al. (2015) reported that the implementation of green initiatives to curtail the CO$_2$ emissions in the shipping industry is slow compared to other sectors and suggested that the combination of existing incremental and novel technologies with renewable energy integration may result in 50% CO$_2$ emissions. Davarzani et al. (2015) presented a review article by consolidating the research works carried out in the green ports and maritime logistics.

In order to overcome the practical limitations of using rigid sails and solar panels on ships, an innovative wind and solar Marine Renewable Energy solution is designed and stated in the review of maritime transport
(2008). The solar power array can be mounted on the sails, deck or both and this will charge batteries or the power will be fed into the DC/AC power distribution system. The energy stored in the batteries could also be a useful source of emergency power. The Eco marine power company in Japan (2009) has developed an innovative system that will allow ships to utilize wind power via a computer controlled integrated system of rigid but movable sails in order to reduce fuel consumption and lower noxious gas emissions. They have also developed another cutting-edge green shipping technology called Tonbo solar-electric ferry or hybrid marine power (HMP) vessel. This innovative design project incorporates the solar module, Lithium battery and electrical power management technology so that the Tonbo's fuel consumption and emission of noxious gases will be significantly less than other ships and ferries of the same size.

Several alternatives are proposed to reduce or to replace fossil fuels onboard a ship: sails, kites, receive electricity in ports, use of biodiesel, wind turbines, photovoltaic modules and biogas CHP systems. The report from International council of clean transportation (2011) under renewable implementation strategies states that most developed wind turbines are those of the Horizontal Axis Wind Turbines (HAWT) type which are highly suitable turbines for generating electrical energy. Their application on ships is very attractive considering that the wind force is greater at harbor region, a better performance is yielded. The technical feasibility of onboard installation can be analyzed based on their main dimensions such as blade diameter, the axis rotation height, base diameter and weight. Also the report states that photovoltaic systems are renewable energy sources with various applications and their implementations in energy production and saving are verified. Installing those systems onto merchant marine vessels could prove to be an
efficient way of minimizing fuel costs and simultaneously protecting the environment by reducing significant carbon dioxide emissions.

Solar Sailor, an Australian company specializing in renewable energy technologies, planned to install its solar and wind power systems on a massive dry cargo ship that could be used to haul iron ore from Australia to China. In the recent years, the research focus is also towards the reduction of fuel demand used for heating water, oil, and marine heavy fuel oil by adapting solar energy resources for shipping sector operation. The idea of gradually substituting conventional fuels, used in propulsion and power generation for merchant vessels, with alternative solutions that use clean or renewable energies, is becoming a reality driven by two fundamental factors. There is an increase in international policy aimed at eliminating the use of polluting fuels in ships (AEA Energy & Environment, 2008). Secondly, the price of these fuels is continuously rising, because of dwindling oil reserves. Glycas A et al. (2010) stated that in search of a “green” ship, an alternative solution identified consists in use of biogas for power generation, biodiesel, wind turbines, photovoltaic solar modules, and distributed CHP systems.

However, ship-owners are skeptical regarding implementing renewable sources of energy onboard ships, due primarily to high costs associated with these technologies. Efforts must be made, generally by policies and special facilities and benefits, for encouraging the development of “greener” ships. Kotrikla et al. (2016) stated that a more effective solution in order to significantly reduce pollutant emissions and improve environmental conditions is to combine cold ironing with renewable energy from wind and sun. They have studied various scenarios and estimated that the total energy requirements of the ships at the port of Mytilene could be covered by a hybrid system of four 1.5 MW wind turbines combined with a 5
MW photovoltaic system.

2.2.1 Survey on use of Bio-Diesel in Diesel Engines

Over the past years, extensive research has been carried out in analyzing the performance and emission characteristics of diesel engine by using diesel-biodiesel blend by varying the proportions. The use of a diesel-biodiesel blend fuel, reduced the total Hydrocarbon (THC) and carbon monoxide (CO) emissions but increased nitrogen oxide (NOx) emissions due to the increased oxygen content in the fuel reported by Ghobadian (2009), Shrivastava et al. (2013) and Kim & Choi (2010). Jain et al. (2011) reported that, the technical disadvantages of bio-diesel/fossil diesel blends include problems with fuel freezing in cold weather, reduced energy density and the degradation of fuel under storage for prolonged periods.

Among the several techniques to reduce exhaust emissions, the use of fuel-borne catalyst was primarily focused due to its advantage of the increase in fuel efficiency while reducing harmful greenhouse gas emissions. The influence of cerium oxide additive on ultrafine diesel particle emissions and kinetics of oxidation was studied by Jung et al. (2005). They found that inclusion of cerium to diesel caused a major reduction in number weighted size distributions and light-off temperature and the oxidation rate was increased significantly. One additional problem is encountered when blends are first introduced into equipment that has had a long history of pure hydrocarbon usage. Hydrocarbon fuels typically form a layer of deposits on the inside of tanks, hoses, etc. Biodiesel blends loosen these deposits, causing them to block fuel filters.
Moreover, fuel pump also suffers badly while operating in biodiesel blends. List of fuel pump problems are 1) Corrosion of fuel injection equipment components. 2) Elastomeric seal failures. 3) Low pressure fuel system blockage. 4) Fuel injector spray hole blockage. 5) Increased dilution and polymerisation of engine sump oil. 6) Pump seizures due to high fuel viscosity at low temperatures. 7) Increased injection pressure.

Riberio et al. (2007) discussed the oxidation stability of biodiesel. The esters of unsaturated fatty acids are unstable with respect to light, catalytic systems and atmospheric oxygen. It is one of the key issues in using vegetable – oil based fuel, and attention is given to the stability of biodiesel during storage and use. These problems could be circumvented by using additives. Hence, conventional liquid fuels with the addition of energetic nano scale materials as fuel additives to enhance the performance and emission characteristics in a CI engine is an interesting and novel concept.

The recent advancements in nanotechnology have a large impact in several applications. Nanomaterials are used to produce either novel or enhanced physical properties. In recent years, several scientists and researchers have applied nanotechnology to the field of fuel engineering. Wen (2010) considered energetic nanoparticles / nanoenergetic (i.e Nanoenergetic materials can store more energy than conventional energetic materials and can be used in innovative ways to tailor the release of this energy. Thermobaric weapons are one potential application of nanoenergetic materials) or suspensions of energetic nanoparticles in a liquid carrier, as a secondary energy carrier. One of the methods to vary the specific fuel properties and combustion of a liquid fuel is the use of nanoadditives. Nanofluid fuel is a new class of fuel with the suspension of nanoscale sized particles (Gan&Qiao
These fuels are known to exhibit different thermophysical properties when compared to conventional liquid fuel.

In this direction, Shaafiet al. (2015) critically reviewed the effect of dispersion of various nanoadditives on the performance and emission characteristics of a CI engine fuelled with diesel, biodiesel and blends. Recently, Shaafiet al. (2015) attempted to study the emission characteristics of the two modified fuel blend namely B20, D80SBD15E4S1+alumina and compared with that of neat diesel. They observed a considerable reduction in the major pollutants such as CO, CO₂, and unburnt hydrocarbon (UBHC) in the case of D80SBD15E4S1+alumina fuel blend compared to neat diesel at full load condition. The authors concluded that alumina nanoparticles enhance the NOₓ emissions, due to the maximum cylinder pressure and higher heat release rate was achieved during the combustion process. Balaji and Cheralathan (2016) performed an experimental investigation to study the influence of alumina oxide (Al₂O₃) nano additive on the performance and emissions of a methyl ester of neem oil-fuelled direct injection diesel engine. The alumina oxide nanoparticles are mixed in various proportions (100 to 300 ppm) with the methyl ester of neem oil and the influence on the performance and emissions at various loads were reported.

2.2.2. Survey on DC Microgrids with Renewable Energy Systems

Corredoret al. (2012) developed a novel hybrid propulsion system of internal combustion engine (ICE) coupled with an electric motor powered by batteries through an electric DC bus device in a parallel configuration system, in order to increase the travelled distance to fuel consumption ratio. Parameters such as boat size, engine hybrid configuration, were simulated. Strunzet al. (2014) proposed a DC microgrid with renewable energy systems.
Further, a new method to quantify the uncertainty affiliated with the forecast of aggregated wind and PV-based power generation was developed and used to quantify the energy reserve of the battery energy storage system. In accordance with the microgrid paradigm, the operation is also supported in autonomous mode in order to support UPS when the connection to the main grid is unavailable. Jayant Kumar (2015) discussed the importance of developing smart microgrids in port owned applications. A new microgrid system is suggested for Philadelphia Navy Yard Alstom. Krkoleva et al. (2010) developed a pilot test microgrid for a rural location. They stated that the pilot microgrid encompasses a part of the existing low voltage grid on the farm, including few loads and a generator. The loads within the microgrid will be supplied either by grid electricity, or by electricity produced by the renewable sources.

Cherry et al. (2014) stated that there is a strong correlation between electrification and rise in human development, but in developing countries access to electricity is often unreliable, unavailable, or unobtainable, especially from a centralized electric grid. They developed an approach of using a biogas digester to supply an internal combustion engine with fuel to generate electricity for portable energy storage devices (PESDs) for portable electrification. Hebener et al. (2016) examined the aspects of terrestrial microgrids and ship power systems. They have also stated that the balancing strategy is an effective tool to improve system-level stability on finite inertia power systems, which is an important consideration in early-stage microgrid and ship power system design studies. Gerry et al. (2013) optimized the distributed energy resources (DER) that includes distribution generation (solar PV array, wind energy, hydro and biogas fuelled generator) with battery backup.
They adopted an approach based on mathematical modelling for each component of DERs and optimization is carried out using HOMER in order to determine the economic feasibility of DERs to ensure reliable power supply to load demand and minimization of cost. The methodology for overcoming several technical challenges in renewable energy systems to isolated applications, were also discussed. Mariam et al. (2013) performed techno economic analysis of micro generation towards the development of community based microgrid systems. This analysis was carried out by them for wind power based micro generation systems that have not attained maturity in renewable energy feed-in-tariff policy.

Hill et al. (2012) stated that integration of energy storage systems into the smart grid to manage the real power variability of solar by providing rate variation control can optimize the benefits of solar PV. The authors have also highlighted that coupling solar PV and storage will drastically increase the reliability of smart grid, enables more effective grid management, and creates a dispatchable power product from available resources. Accelerated development of eco-friendly technologies such as RES, Smartgrid, and Electric Vehicles are finding increased economic and social acceptance. Planning an efficient electric power system requires consideration of these technologies in the design stage.

Therefore, they introduced a method for sizing a hybrid RES operating within the frame of a smart grid that coherently considers the electric demand flexibility offered by Demand Side Management. Tan et al. (2013) stated that microgrid is the indispensable infrastructure of nowadays smart grid, however, the fluctuation and intermittence resulted from unstable micro-sources and nonlinear loads will execute considerable impacts on normal operation of the MG. They highlighted that the energy storage
technology presents a preferable solution to the above issue. Fossati et al. (2015) proposed a genetic algorithm-based method for sizing the energy storage system (ESS) in microgrids. The main goal of the proposed method is to find the energy and power capacities of the storage system that minimizes the operating cost of the microgrid.

2.3 INFERENCES FROM THE LITERATURE SURVEY

It is understood from the above studies that maritime transportation plays a vital role in a country’s economic status and evolution in terms of the trade. The other thing well observed from the above studies is that the market for seaport transportation keeps evolving and it is going to be a more energy intensive sector than it is now. This driving force made the several researchers and the governments to work towards the green port concepts. Several organizations such as World Port Climate Initiative (WPCI), World Ports Climate Declaration (WPCD), International Maritime Organization (IMO), United Nations Framework Convention on Climate Change (UNFCCC), European Sea Ports Organization (ESPO), International Association of Ports and Harbors (IAPH) are working together to mitigate the GHG emissions from maritime transportation and activities.

In addition, the IMO has developed a protocol named International Convention for the Prevention of Pollution from Vessels, generally known as ‘MARPOL’ to globally address the problems( IMO, 2014). Apart from the efforts taken by the respective governments, researchers are also working on par with the governments to downsize the maritime emissions.

It is inferred from the detailed literature survey that several research works have concentrated on accounting the GHG emissions from several port
activities by following different approaches. In that, most of the works have been carried out in western and European countries. Only a few studies have been carried out in developing countries. To the author's knowledge, there are no such studies carried out for Indian ports. Considering the fact that there is no GHG inventory developed for any of its seaport activities, in the present work, a detailed GHG inventory is created to estimate the carbon footprint by the port of Chennai for the financial year 2014-15.

Further it is observed from the literature that, the combustion behavior of conventional liquid fuels with the addition the energetic nanoscale material fuel additives enhance combustion and engine performance, and control emission characteristics in a diesel engine that provides an interesting concept for study. Also several opportunities are possible like energy efficiency measures in equipment, management policies and implementation of renewable energy technologies to mitigate the GHG emissions. Community level DC microgrid feasibility is also explored in certain ports.

Considering the above scenario, the following objectives were formulated for the present research

- To carry out an inventory of greenhouse gas (GHG) emissions by following WPCI(2010) and IPCC (2014) guidelines in the port of Chennai, by accounting the energy consumption by various port facilities along with the housing areas and fishing harbour.

- To explore possible ways of CO₂/GHG mitigation through the use of energy efficient equipment, by practicing the energy conservation measures and utilization of renewable energy sources.
• To investigate the effect of the Diesterol blend with cerium oxide fuel on engine emission characteristics and a comparison is made with neat diesel which is highly suitable for port and shipping sectors.

• To study the potential to implement the recent advances in the field of solar and other renewable energy based technologies with the concept of DC microgrid.