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The application of renewable energy supply in a port container terminal : Bandar Abbas Port container terminal case study

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THE APPLICATION OF RENEWABLE ENERGY SUPPLY IN A PORT CONTAINER TERMINAL

Bandar Abbas port container terminal Case study

by

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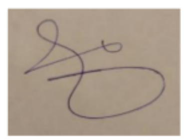
Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): 

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"You must be the change you wish to see in the world"
Gandhi

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Abstract

The application of renewable energy supply in a port container terminal Bandar Abbas port container terminal Case study

Master of Science

The need for energy and its related services to satisfy human social and economic development has been increasing over the last few decades. One of the key stakeholders contributing to this increase in energy consumption are the seaports and they are significant contributors towards the deterioration of the environment because of the increasing amounts of Greenhouse Gases emitted by their activities. Renewable energies are sustainable sources of energy which are abundantly available with minimum carbon footprint. This study deliberates on various renewable energy sources those could be used for ports. However, the research focuses on container terminal at port of Bandar Abbas, Iran to ascertain the most feasible renewable energy sources which will ensure meeting port's present and future energy needs in a sustainable manner. Evaluation of different options revealed that wind and solar appear as the two most promising renewable energy sources for the aforementioned port. According to a holistic approach, systematic literature review and applying the Multiple Attribute Decision Making (MADM) model and TOPSIS method, it was concluded that onshore wind energy is the best renewable energy option to mitigate greenhouse gases from the container terminal, as this option is the most economical one with the minimum cost of energy per unit, and the least carbon foot print, besides having maximum stability in terms of availability. According to the port expert's opinions (obtained from Questionnaire), the study has also put forth some measures and policy recommendation which when considered by the port authority would help them achieve the aim of port sustainability. The challenges of effective implementation of energy efficiency actions were also highlighted and paved the way for further study to confront them.

KEYWORDS: Port Emissions, Energy Efficiency, Energy Management, Carbon Footprint, Renewable energy, Climate Change, The Technique for Order of Preference by Similarity to Ideal Solution, Multiple Attribute Decision Making

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List of Abbreviation

CO_2	Carbon Dioxide
GHG	Green House Gas
IMO	International Maritime Organization
MARPOL	International Convention for the Prevention of Pollution from Ships
UNFCC	United Nation Framework Convention on Climate Change
UNCTAD	The United Nations Conference on Trade and Development
MEPC	The Marine Environment Protection Committee
OECD	The Organization for Economic Cooperation and Development
NO_x	Nitrogen Oxide
SO_x	Sulphur Oxide
PEMP	Port Environmental Management Plan
ESPO	European Sea Port Organization
EMS	Environment management System
TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
EEA	The European Economic Area
PMO	Port and Maritime Organization
SDS	Sustainable Development Scenario
IEA	International Energy Agency
OWT	Offshore Wind Turbine
COP	Conferences of Parties
NDC	Nationally Determined Contributions
GPA	Genoa Port Authority
PEEP	Port Energy Environmental Program
HPA	Hamburg port Authority
PEMP	Port Energy Management Plan
MADM	Multiple Attribute Decision Making
GPM	Green Port Management

1 Introduction

The world has woken up to the fact that climate change is increasing due to human activity. Green House Gas emissions which are the result of human activity results in temperature rises on Earth. Scientists believe that even if we keep these emission levels low, which is a struggle, we will still experience global warming by the end of the century. This causes Greenland`s ice sheets to melt, overflow in coastal cities, droughts in crop growing areas and people being faced with a range of diseases. The only way to prohibit the abovementioned hazards is to significantly reduce GHG emissions (Fry, C. 2008).

1.1 Background

Shipping accounts for 80% of worldwide transportation by volume and plays an important role in global economics (UNCTAD, 2017). Shipping is responsible for 3.3% of the global emissions of carbon dioxide (CO_2). However, this might grow by 150% to 250% by 2050 due to shipping fleet growth. Furthermore, utilizing more efficient technologies, renewable and cleaner types of energy by other industries can make a contribution to shipping of 12% to 18% in global CO_2 emissions by 2050 (IMO.MEPC, 2009). The International Maritime Organization by adopting a strategy framework to mitigate GHG emissions by at least 50% by 2050 compared to 2008 is a clear declaration of their priorities (Comer et al, 2018). Meanwhile, the IMO encourages the states to transfer and share their innovations and more efficient technologies to help in the mitigation of emissions (IMO, 2017).

Ports play a crucial role in the shipping industry. They are the gates to the cities and connect the world through maritime transportation. Moreover, they support international trade economic growth. However, ports have negative externalities in consequence of ships activities and cargo handling. Port-related GHG emissions account for only 2% of total shipping CO_2 emissions but they are projected to rise four-fold by 2050 if business as usual continues (Merk and Olaf, 2014). It is crucial that appropriate action has been taken to control and mitigate these negative externalities within the ports.

Containerization in the shipping industry has a profound effect on the port structure and port operation, and it modified some of the traditional port functions. Today, the container terminal industry is under a great deal of pressure to meet economic and environmental standards. This industry's levels of energy consumption and the resulting emissions are significant but, despite increasing energy consumption rates and costs, few energy efficiency measures or strategies are in place in today's ports and terminals. (Wilmsmeier & Spengler, 2016).

Shanghai and Singapore, the world's busiest ports have a throughput of 43.3 and 37.2 million TEUs respectively (2019). For handling huge volume of containers efficiently in ports without affecting the vessels' turnaround time, efficient cargo handling equipment and facilities must be in place (UNCTAD, 2017). Energy efficiency is a strategy and a sure way to reduce the emissions mentioned above in the shipping industry. It is impossible to reach zero percent of emissions but considering energy efficiency and the utilization of renewable energies they are the key to reducing the cost of shipping, protecting the environment from climate change, and achieving sustainability in the maritime industry.

On the other hand, energy efficiency is becoming more interesting for ports and terminals as they have realized that substantial energy savings can be obtained through the rationalization of operations, adoption of new technologies, and use of renewable energy sources (European Sea Port Organization (ESPO), 2012). One of the most critical ways for making a port more energy efficient and sustainable is by using renewable energy. Renewable energy "generated from natural resources such as sunlight, geothermal heat, wind, ocean, water, is constantly replenished and cannot be exhausted (Coilkosz,2017)." Renewable sources for electricity generation is inevitably estimated to have a growth of more than one-third by 2022, IEA (2012) reported.

According to (ISO, 2011), because of increasing energy consumption by industries like the ports, there is a need for better and more efficient energy management systems with clear policies and guidelines for implementation. Also, ISO 50001 (2018) introduced some criteria for energy management to improve and implement the efficiency inside of an organization like port.

1.2 Problem Statement

Sea ports act as one of the main parts of the maritime supply chain. They provide a large number of services to society. However, these services cause conflicts between human activities and the environment. As much as ports are busier, there is a higher risk of pollution. Ships threaten the sustainable development of ports by their negative environmental and socio-economic impacts (Badurina et al, 2017). Furthermore, Ships' emissions effect 230 million people who live within the top 100 ports (Merk and Olaf, 2014) and only in California, 3700 premature deaths per year are due to ports and the shipment of goods (Sharma, 2006), as well as it imposed €12 billion per year of external costs to the 50 largest ports in the OECD for NOx, SOx and PM emissions (Merk and Olaf, 2014). In order to support a sustainable port and sustainable shipping for a sustainable planet(IMO, 2020) it is required that human activities within the port are limited, regulated and that negative anthropogenic activities are minimized to enhance economic growth and environmental protection simultaneously. As CO_2 emissions are due to port operations it is one of the main sources of air pollution in seaports, so in order to reduce its ramifications, ports need to adjust terminal operations and other possible solutions might be utilised for renewable energy instead of fossil fuels as a good alternative energy source for operations in ports. This study attempted to select suitable option of renewable energy to diminish CO_2 emission within Bandar Abbas port container terminal, the most important commercial port of Iran.

1.3 Research Objectives

The main objective is to apply the best renewable energy options to lessen the carbon footprint within a container terminal in a developing country (Iran, Bandar Abbas port container terminal) based on the holistic and systematic literature review.

1.4 Research Questions

The research methodology aimed to answer the following:

Question one: What renewable energy options are feasible for use at a port container terminal to reduce its carbon footprint?

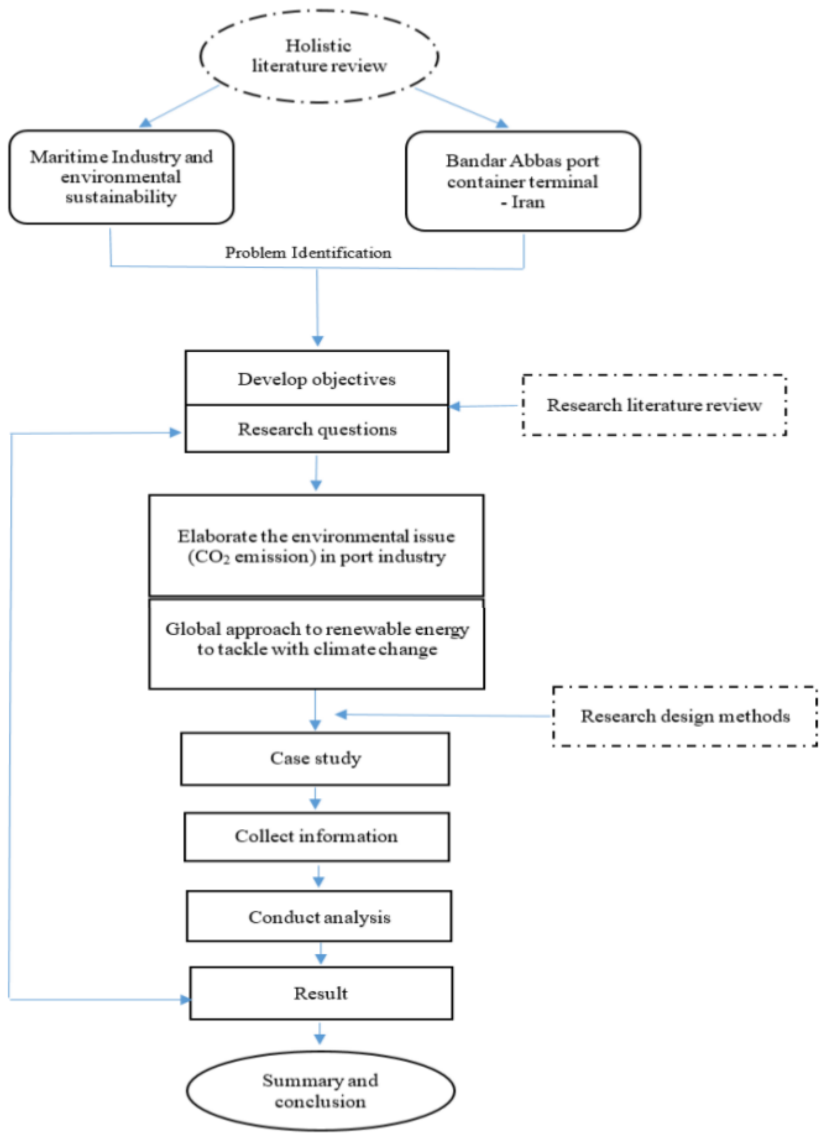
Question Two: What are the other feasible options available, for the port container terminal to reduce its carbon footprint?

1.5 Research Methodology

For the study first of all a holistic approach was taken considering a systematic literature review of various resources were conducted and after classifying the data, qualitative analysis was done. Meanwhile, in the case study, the quantitative data for energy consumption of the Bandar Abbas port container terminal was analysed. Moreover, the CO_2 emissions and the possibility of producing renewable energy in the Bandar Abbas port container terminal was considered. Finally, using the qualitative and quantitative methods to select a reasonable option for renewable energy in the Bandar Abbas port container terminal and also the measures that will help the port authority to increase energy efficiency and reducing CO_2 emission were suggested.

Figure 1

Research Design



Source: Author, 2020

1.6 Research Outline

The research consists of six chapters organized as follows:

Chapter one contains the introduction, problem statement, objectives, research questions, methodology, outline and limitations of the study.

Chapter two the existing literature was reviewed according to what has been introduced and what will be surveyed and analysed. The research that has been done on port energy management, efficiency, renewable energy, planning, and monitoring and proceeding to the environmental requirements that have been reported.

Chapter three explains the methods used to collect and analyse the data and elaborates the methodology that was used for trade-off analysis in developing the case study.

Chapter four elaborates on the legal frame work and policies related to the reduction of the carbon footprint, seaport energy management, the environment plan and renewable energy.

Chapter five is the case study that presents the suitable renewable energy option by the trade-off of the environmental (CO_2 emission) and economical aspects and help the decision makers choose the best option to improve the sustainability of the port s.

Chapter six is the conclusion and recommendations.

1.7 Research Limitations

1.7.1 Collecting Data

One of the problems for students undertaking academic research, especially analytical ones, by their case study and different questionnaires, is the collection of primary data. Access to accurate and update data may also be difficult due to some reasons like sanction and disease outbreaks as a prominent example of the Corona Virus. The author of this dissertation has dealt with some of these issues as well.

1.7.2 Time Limitation

Time management is a concern of all researchers, and the author of this research is no exception to this. Planning and managing time can be a challenge. Whether or not, by involving other people in a study, a researcher will sometimes face time variables in managing it. Those who are unprofessional in their field of activity can have a negative effect on the timing of the project.

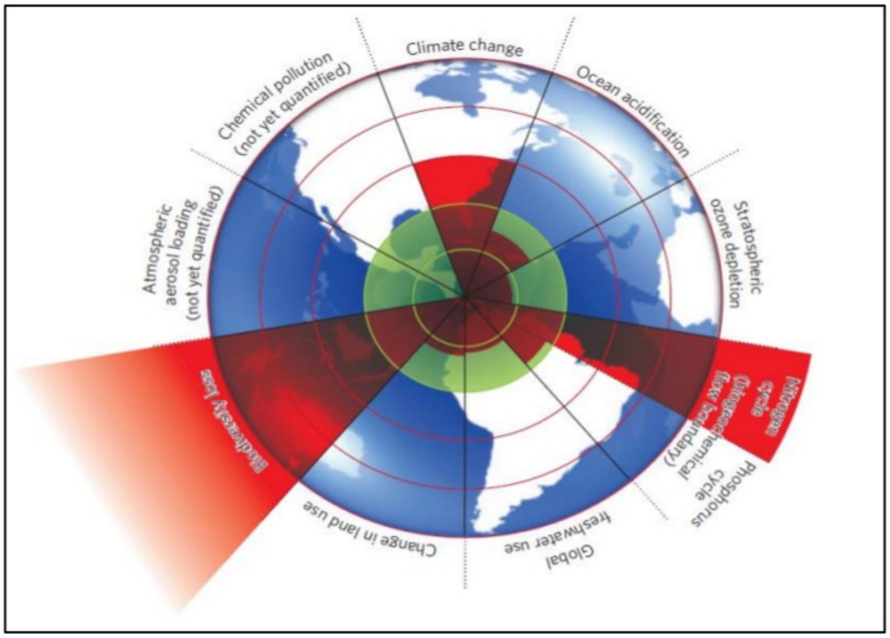
2 Literature Review

2.1 Introduction

Global warming and climate change are regarded as one of the most significant threats on the environment, however both these terms are not well understood by the various stakeholders. Though these terms are used interchangeably, they have a distinct meaning. Global warming is a term used to denote the heating of the earth's climate system dating back the pre-industrial period i.e. in 19th century from 1850 to 1900. Global warming is primarily caused by human activities especially burning of fossil fuel which causes an increase in the concentration of heat trapping Green House Gases (GHG) in the earth's atmosphere. The earth's average temperature has increased by about 1 deg C from the pre-industrial levels and this is an increases at the rate of about 0.2 deg C per decade. This increase has been primarily since 1950's when human activities increased unprecedently. Climate change on the other hand is the long-term change in the weather pattern of an area including in context of local, regional and global. Climate change is caused not only by human activities responsible for global warming but also by other natural activities like, El Nino and La Nina cyclic ocean patterns, volcanic activity, changes in the sun's energy output, etc. (Overview: Weather, Global Warming and Climate Change, n.d.). Geologist believe that the Holocene era which is the period of stability of earth may now be under threat. Since the industrial revolution, human activities have pushed the earth system outside of the stable environmental state of the Holocene. Human activities have reached a level that could damage the earth (Van Der Veen et al., 2011). As the following figure depicts, we have already overstepped three of the planetary boundaries.

Figure 2

Planetary Boundaries



Note. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded (Van Der Veen et al., 2011).

Maintaining the long-term environmental stability of the Holocene, some experts suggest, will require respecting nine interlinked planetary boundaries that define a "safe operating space" for humanity (IGBP,2009).

Seaports are essential stakeholders in the maritime transport network and are the cause of large amounts of GHG emissions owing to their large consumption of fossil fuel. Although it is argued that ports form a small part of shipping GHG emissions, studies have indicated that seaports account for about 3% of global GHG emissions. Further, it may be noted that CO_2 emissions account for about 72% of the total GHG emissions from burning of fossil fuels(Gibbs et al., 2014). Hence, for a nation to be able to meet its Nationally Determined Contributions (NDC) targets regarding GHG emissions, under the Paris Agreement, it is imperative that it reduces carbon footprint from its seaports. In order to move towards green ports and surge the environmental performance of ports, some studies specify that port governance models play a significant role. They highlighted that among four port governance models, the most viable one for the implementation of green port management would be private port and tool port at the least. Although some believe that private firms concentrate on profit generation and are not so interested in the environmental aspects it found that green port management positively influences port performance and it maximises the profit indirectly (Munim et al., 2020).

2.2 Renewable energy as a source for reducing carbon footprint

Renewable energy is often known as clean energy, and it is available in abundance as it comes from natural sources which are constantly replenished. Though humans have been harnessing renewable energy for hundreds of years, now with innovation and technology it has become possible to harness renewable energy economically and efficiently, especially solar and wind power(Owusu et al., 2016). Globally the usage of renewable energy has been growing for the last few decades. There are six kinds of renewable energy sources i.e. solar energy, wind energy, hydroelectric energy, biomass energy, geothermal energy, and tidal and wave energy(Renewable Energy: The Clean Facts, n.d.).Traditionally the electrics in seaports are supplied by electricity from the utility grid which uses a mix of coal, oil and gas for electricity production, which produces emissions resulting in the release of GHG's in the atmosphere. The integration of energy harnessed from renewable sources using smart grids will reduce the seaports consumption of electricity produced using combustion of coal, oil or gas, thereby reducing GHG emissions. Hence, the usage of renewable energy in ports would lead to its reduced carbon footprint (green port, n.d.). In order to reduce the carbon footprint, seaports can use renewable energy sources such as solar energy or wind energy. Another option for them is to use energy sources which have less carbon content. Power generation from renewable sources depends upon the environmental conditions (e.g. weather, geologic conditions), and the location of power production. Further, cost estimation is also important as it includes capital costs and operating costs. However, renewable energies operating costs are mainly limited to maintenance costs as the sources of renewable energies i.e. wind, sun, geothermal heat etc. are unlimited, free of cost and available in abundance. Hence, as the cost of fossil fuels increase, usage of renewable energies becomes more attractive economically. Further, government subsidies also play an important role in the investment decisions (Savage et al., 2004). Efficiently managing energy at seaports not only contributes to reduced greenhouse gas emissions but also results in saving energy costs, thereby lowering the operational expenditure (Schwientek, A., & Jahn, C. (2012).

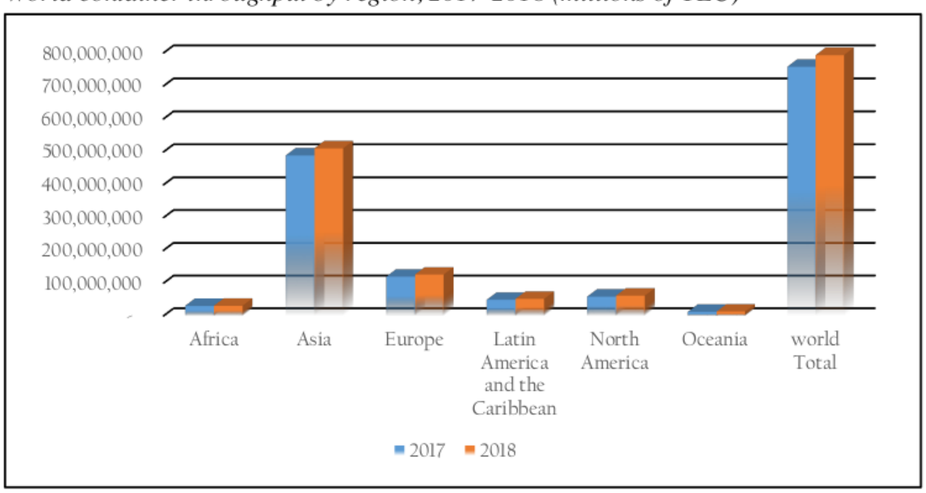
In China, Europe, and the United States, renewable energy production has been taken seriously for about ten years. Initially, the cost of investing in renewable energy, mainly of which is wind and solar, was very high, and then the cost has decreased over time. Governments, including Germany, gave a lot of support to renewables, which led to the development of technology in this area. Energy production plays a key role in development, and today countries are turning to the development of renewable energy to be rid of energy losses from fossil fuels; So that 2.8 of the total energy needs of the world are met by this type of energy. Solar energy is one of the most important sources of renewable energy, and today China (18%), Japan (14%), Germany and the United States (more than 13%) have turned to this source to meet their needs. Iran has a good capacity to produce solar energy with 300 sunny days and a total area of 1600 square kilometres or 1.6 by 10 square meters. However, the total production of renewable energy in wind, solar, biomass and geometric has reached 420 MW, which is not a large figure considering the production and need of 70,000 MW of energy in the country (Najafi et al., 2015).

2.3 Energy consumption trends in the maritime sector including ports

Shipping is the backbone of international trade and it plays a crucial role in the economic growth of an area or nation. Although it is the most efficient type of transportation, it has negative externalities as well. One of the most significant externalities is the GHG emissions. Improving energy efficiency and reducing GHG emission in the shipping industry is a challenging task and requires synergy and co-operation of all the stakeholders (Martínez-Moya et al.,2019). Ports being one of the important stakeholders in the maritime industry, also play a crucial role in the economic growth of the nation, while also providing various types of services (Aregall et al, 2018). It is a known fact that, while shipping industries maximum emissions occur at sea, however the most directly noticeable emissions occur at port areas (Merk and Olaf, 2014). In regards to container terminals, though they contribute towards economic growth, keep their services competitive, however they have a huge negative impact by way of the large amount of GHG emissions when compared to ships in general (Dowd & Leschine, 1990). Figurer 3, indicates that the total trade volume of containers is increasing at a steady rate, requiring more energy in years to come.

Figure 3

World container throughput by region, 2017-2018 (millions of TEU)



Source: UNCTAD,2019

European Sea Port Organization (ESPO), considers air quality and energy efficiency as the top two priorities among their top ten environmental priorities (Sdoukopoulos et al, 2019). The focus on energy consumption lead to about 60% of European ports developing and implementing energy efficiency programmes. For example, the port of Antwerp implemented measure to get certified for ISO 50001. In addition, about 20% of European ports are promoting the use of renewable energy to reduce their carbon footprint. Furthermore, there are other ports such as Los Angeles, Antwerp, and Genoa, who have developed and implemented the Port Energy Management Plan (PEMP). Energy is critical to the current and future sustainability of ports. Ports are going to rely more upon electricity to move cargo, rather than the dependence upon fossil fuel as done in past (Burns & McDonnell,2014). According to The European Economic Area (EEA), 2017 Energy efficiency is simply the delivery of more energy output from less energy input, however Farrelln (2017), argues that there is no particular style of solution for achieving energy efficiency which will work for all the countries. Thereafter, EEA (2017) introduced the setting of targets, developing national strategies, and having institutional frameworks and effective policy packages necessary to be used in the ports management system. The combination of key measures such as regulations, economic incentives, voluntary agreements, information instruments, trustworthy data, capacity building, enforcement, monitoring and evaluation, the desired and expected energy efficiency improvement would occur (Chai & Yeo,2012). Studies done on port energy management tend to focus on port energy efficiency, alternative fuels, and the environmental impact of port operations. Seaports environmental sustainability is as a rule and base for maritime policy and management. They believe "Environmental sustainability in the port industry is of growing concern for port authorities, policymakers, port users and local communities". Innovation can provide a solution to the main environmental issues but often meets resistance". The drivers for energy efficiency went back to some countries like the United Kingdom and Japan (Acciaro et al., 2014). Today, drivers for energy efficiency in the maritime sector are classified into regulations, economics, and environmental factors (IMO, 2015). According to IMO (2015), regulations are seen as the most effective measure as it creates equal opportunity and aids organisations to develop broad-scale measures and technologies to reduce emissions and improve energy efficiency. Energy efficiency is not a new issue, but in the case of ports, despite the increase in the number of projects related to energy saving and renewable development, no special realization has taken place on this issue. However, in the manufacturing sector, intermediary companies and alleys, universities, and in shipping and other sectors, effects on energy efficiency are taking shape and forming.

2.4 Port of Genoa

The Genoa Port Authority (GPA) has developed a Port Energy Environmental Program (PEEP) to stimulate and develop renewable energy activities. The rationale behind this plan is based on the belief that, what happens when they have an impact on the host city? GPA did a study of large port areas to find how energy wastage has to be reduced and where systems for generating energy from renewable sources are to be installed. A technical committee has used a two-layers method to implement this estimation. One layer focuses on the city, while the other layer focuses on the special buildings. The ultimate goal of PEEP, which was considered as the primary tool in Italy to improve the use of non-renewable resources and increase energy efficiency in port areas, is to reduce 20,000t carbon dioxide per year in the port of Genoa with a total investment of 60 million euros. The port area has features that make it ideal for research on geothermal energy production, such as a seawater-powered heat pump system. An example of such a system was installed at the waterway terminal. Likewise, the port of Genoa offers a wider application of geothermal energy. Five different projects have been implemented in the port of Genoa with a private license dealing with solar and photovoltaic technology. Even if the port has special powers within the premises, these areas have the privileges of a terminal operator, and therefore private operators are those who can now take initiatives that should be aligned with PEEP strategies; develop to act as a coordinator and governor of all energy-related initiatives. There should be the simplest choice in the framework of action for the GPA to implement these initiatives unilaterally and independently, despite the consideration of the restrictions imposed by the Italian law 94/94, regarding the ability of port officials to conduct direct commercial operations; besides, the GPA can only act as a coordinator. Private companies will be outsourced after operational and commercial developments due to their better ability to manage the planning and the responsibility aspects of introducing renewable energy sources. The main result of PEEP was the creation of awareness among terminal operators and their presentation of guidelines that did not exist in the field of energy storage and sustainable development(Delponte et al., 2017).

2.5 Port of Hamburg

The port of Hamburg is also investing, which can apply methods to improve consumption patterns as well as clean energy, including a 53 MW wind farm consisting of 58 wind turbines and the installation of photovoltaic systems to use solar energy with a capacity of 500,000 kw per year to reduce CO_2 production more than 24%. Sustainability plays a major role in the port of Hamburg because the proximity of port areas to the city and the sensitivity of the Alb River ecosystem requires special attention to sustainability issues in port development. In particular, sediment and water quality, climate protection, air emissions, and energy efficiency are the main environmental issues that the port must address. The City of Hamburg is the sole shareholder of the HPA (Hamburg port Authority), thus ensuring that environmental goals are an integral part of the HPA strategy. Since 2011 HPA has been a member of the Hamburg Environmental Trade Board, collaborating with the Chamber of Commerce, Aviation and Commerce Office, the Hamburg City, and Industry Association to improve the environmental balance in the city of Hamburg and generally consolidate coordination between environmental protection and success. Also, HPA, in collaboration with the Ministry of Foreign Affairs, Economic Affairs, Transportation and Innovation, and the Ministry of Urban Development and Environment, has launched an energy cooperation project aimed at developing sustainable energy solutions to improve energy production. The port of Hamburg and the city of Hamburg have been investing in renewable energy since the 1990s when Hamburg pioneered the development of wind energy.

Hamburg Port Authority ‘s approach to grow the port in a sustainable manner is using the modern IT- supported transport and communication systems to accelerate traffic and managing them more efficiently and simultaneously applying renewable energy and saving resources. Based on this view the Smart port energy was initiated in port of Hamburg with three pillars: New innovative technologies, increased energy efficiency, New innovative mobility concepts. A cleaner environment by reducing emissions and gaining economic advantages by a decrease in energy consumption and energy cost are the ultimate goals of the project (HPA goes smart PORT Klarer Kurs auf Steering towards efficiency, n.d.).

2.6 This Research

Based upon the literature review conducted, i.e. the usage of renewable energy in reducing the carbon footprint of a seaport, the objective of this research is to ascertain the most feasible and sustainable renewable energy option for the port of Bandar Abbas (container terminal), Iran.

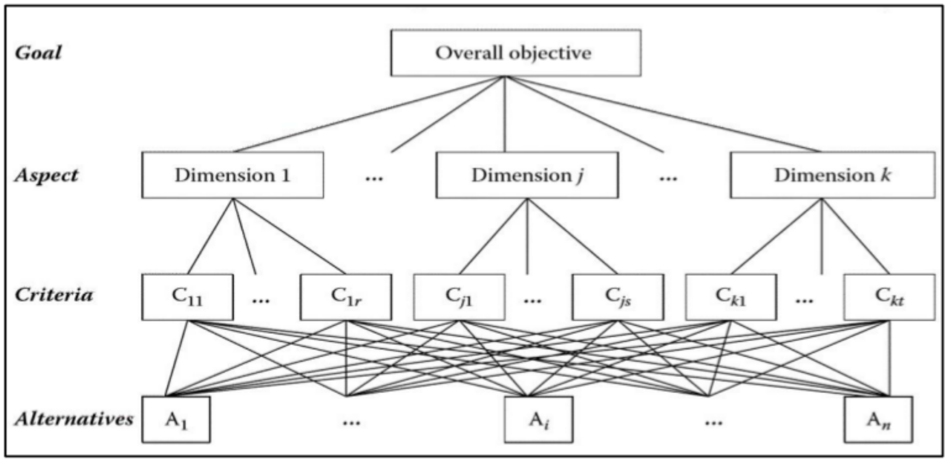
3 Methodology

To achieve the objective of the research, after systematic research, two groups of data were collected. Primary data was collected using the Questionnaire (see **Appendix A**) and also from annual reports (2015-2019) of pertinent organizations such as Bandar Abbas port (Iran) and Renewable energy and energy efficiency organization (Iran), The secondary data was gathered through extensive desk searches for journal articles from Science Direct, Google Scholar, and official organization websites such as IMO, Port and Maritime Organization of Iran (PMO), and others, previous publications available in the WMU library both hard copy and soft copy were reviewed. They were divided into qualitative and quantitative according to a holistic approach. Then a comparative analysis was conducted of them. The Qualitative analysis was used for the conceptual and understanding aspects of the subject and the quantitative used for modelling, simulations, algorithms, and numeral analysis.

In this research four scenarios were presented. To make the comparison, based on the collective data, the criteria were determined. Then to select the best alternative option of renewable energy for the container terminal, the Multiple Attribute Decision Making (MADM) model was applied. In general, Multiple Attribute Decision Making (MADM) is used to select the best option.

Figure 4

Hierarchical system for MADM

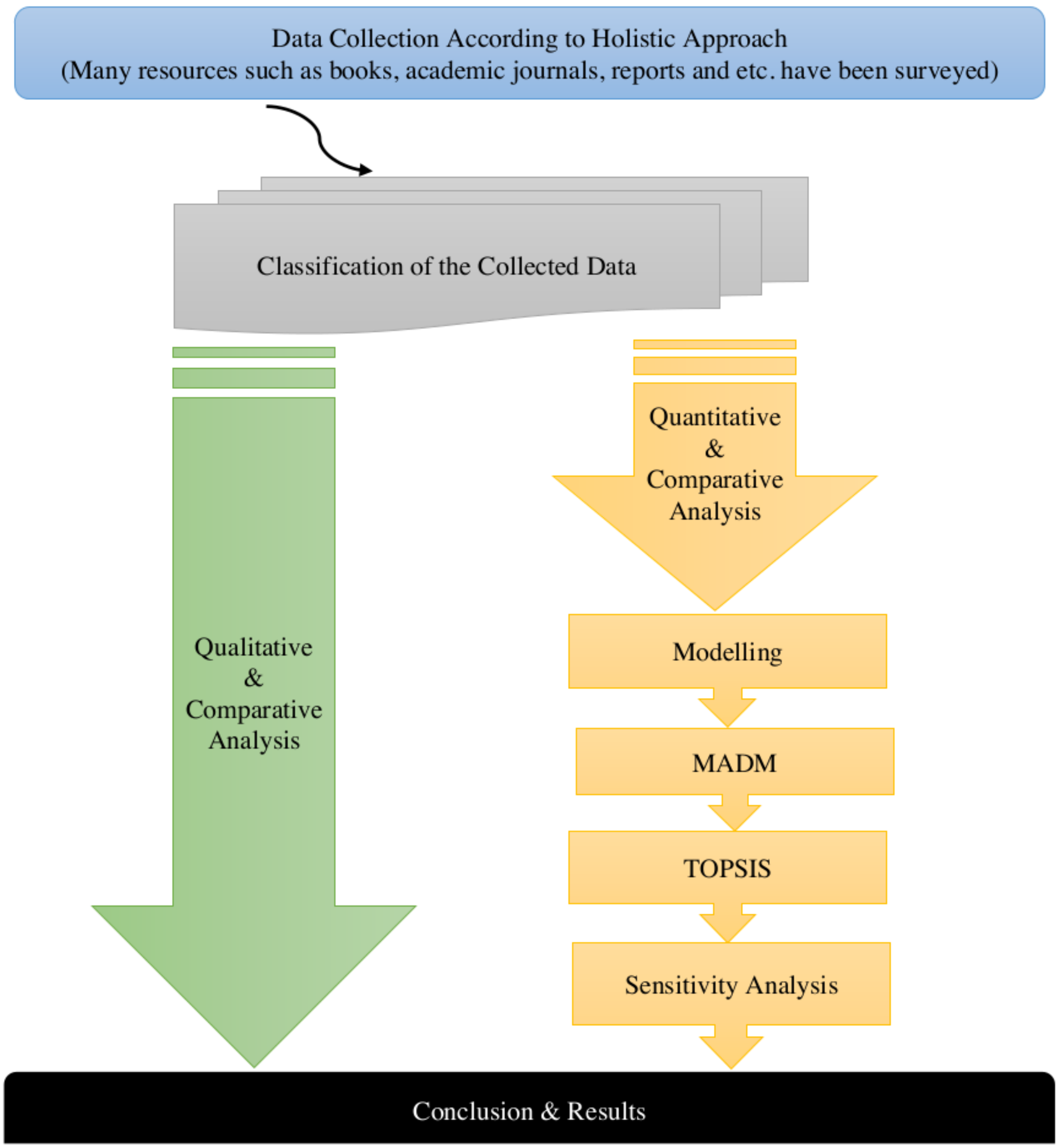


Source: (Tzeng & Huang, 2011)

In Continue, by creating algorithms and applying the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) technique, the best alternative based on the trade-off between cost, CO_2 emission, and amount of renewable energy production was identified. The TOPSIS method is one of the multi-attribute decision-making models (MADM) that considers the ranks of options. The TOPSIS was developed by Hwang and Yoon (1981) to identify the best alternative based on the solution which is nearest to the ideal solution and far away from the negative ideal solution (Zyoud et al., 2017). In the TOPSIS method, the most effective alternative is made from the various attribute values and may even consider invented alternatives. Using data achieved in TOPSIS techniques, a sensitivity analysis was conducted for each various options. And finally, the best option for applying renewable energy to the Bandar Abbas port container terminal to reduce the CO_2 emission was suggested. A detailed scheme of how it was done was illustrated in the following figure 5.

Figure 5

scheme of research (details of research method)



Source: Author, 2020

4 Legal Framework

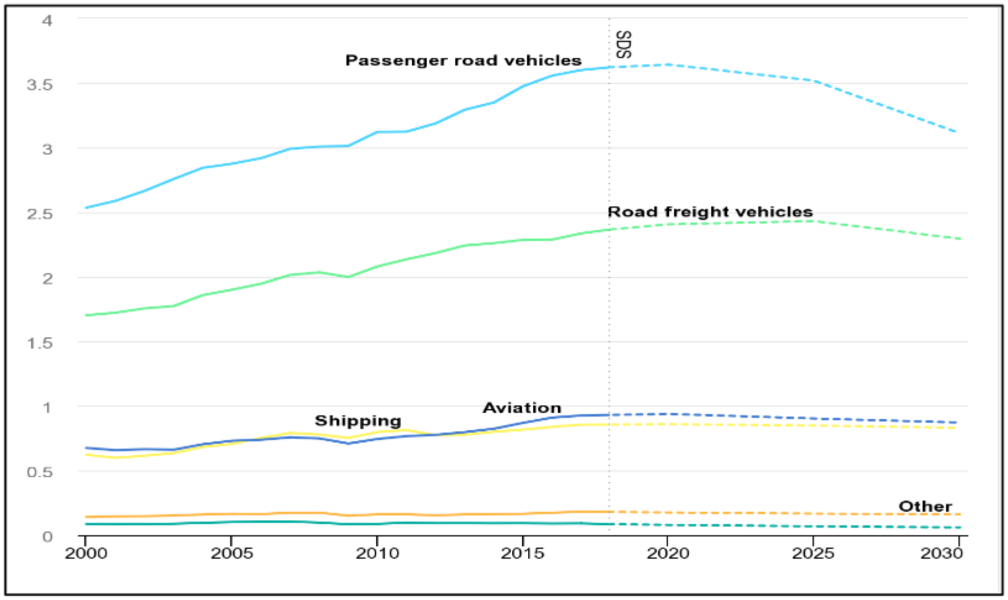
4.1 International level

Late in 19th century, countries started recognising the problem of global warming leading to adverse climate changes, and states began to look at feasible solutions to this problem. The United Nations Framework Convention on Climate Change (UNFCC) was formed in 1994, all in all there are 197 countries who have ratified this convention and are called parties of the convention or nation states. This convention deals with the prevention of human activities that have adverse effects upon earth's climate system (UNCC, n.d.). Parties of the convention meet on a regular basis every year at the meeting called the Conferences of Parties (COP). 21st COP, which was held in Paris in 2015 is of historical importance as, it resulted in the Paris Agreement, 2015. Like Kyoto Protocol and the Doha Agreement, the Paris Agreement also falls under the frame work of UNFCC. The Paris Agreement was a long process with negotiations starting in Durban at COP17 and finally agreed on at COP21 in Paris in 2015 and finally entered in force on 4 November 2016. The Paris Agreement's common aim is to strengthen the global response to climate change threats, by keeping the average global temperature rise to well below 2 deg C, with the aim of 1.5 deg C above the pre-industrial levels. Further, it deals with measures to strengthen the nations response to climate change. In order to achieve its goals, it outlines, the required new technology framework, capacity building, financial flows, in a transparent and efficient manner. It requires all parties to put forward their national plan to achieve the global target of temperature rise through Nationally Determined Contributions (NDC).

Thereafter, global stocktake would be done every five years which would not only access adequacy of NDC's against common global target but also progress the NDC's as declared by the parties(united nation climate change, n.d.). International standard organization (ISO) has designed the ISO 50001 standard, with an aim of empowering organizations to create system for improving energy efficiency. This would also lead to the reduction of GHG emissions, the cost of energy and other ramifications related to the environment through the energy management system. It also provides a structured approach for more efficient use of energy, fixing targets for meeting policy objectives, using the data for better understanding and decision making about the energy usage, measuring and review of the results to ascertain measures required to ensure continual improvement of the energy management (ISO- ISO 50001, n.d.). The aforesaid standard is also linked to the ISO 14001 standard, which specifies the requirement for an environmental management system that an organization can use to enhance its environmental performance (ISO - ISO 14001:2015 -, n.d.) .Studies indicate that the maritime industry along with aviation industry is expected to become one of the fastest growing sectors in terms of GHG emissions (Gilbert et al., 2010). Figure 6 illustrates the CO_2 emission in different parts of the transportation industry during the last two decades and a prediction for next decade.

Figure 6

Transport sector CO_2 emission by mode in the Sustainable Development Scenario, 2000-2030



Source: IEA,2019

One of the main reasons for an anticipated increase in global GHG emissions is the expected increase of the demand on shipping and related services. International Maritime Organization through its 75th session of marine environment protection committee (MEPC 75/7/15) emphasised a reduction of GHG emission from ships. The fourth IMO GHG study 2020, highlighted that, the GHG emissions of total shipping (international, domestic and fishing) has increased 9.6 % from 2012 to 2018. Specifically, the quantity of CO_2 emission had been 962 million tonnes in 2012 (Li et al., 2012) while it has increased to 1,056 million tonnes in 2018. It indicates that the share of shipping emissions in global anthropogenic emissions has picked up from 2.76 to 2.89 within six years. Reducing emissions is now one of the priorities of the IMO. In order to tackle emissions from shipping industry, IMO has adopted Annex VI of the International convention for the prevention of pollution from ships (MARPOL). It aims to achieve it by improving energy efficiency and reducing GHG emissions by other technical measures. Today, a number of policies and regulations have been adopted at the international level, regional level and at the local level to minimise the damages to the environment, caused by human activities. Regarding energy efficiency United Nations Sustainable Development Goal (UNSDG) #7 i.e. ‘affordable and clean energy’ has set various targets to achieve its objective (United Nations, 2019). It aims to substantially enhance the share of renewable energy in the global energy mix, double the global rate of improvement in the energy efficiency, increment of international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology. It also aims to promote investment in energy infrastructure and clean energy technology, and expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries and developed countries.

The UNSDG #13 i.e. ‘climate action’ its objective is to tackle climate change and its impacts. It aims to achieve its objectives by strengthening resilience and adaptive capacity to climate-related hazards and natural disasters in all the countries, integrating climate change measures into national policies, strategies and planning, improving education, awareness and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning, and by promoting mechanisms for raising capacity for effective climate change-related planning and management (United Nation, n.d.).

4.2 Regional level – European Union

The European Commission (EC) has set energy efficiency as a high priority, in 2014 the European Council according its energy strategy 2020 agreed on a new 2030 climate and energy framework with three objectives. Firstly, at least 40% reduction in GHG emissions when compared to 1990 levels. Secondly, increasing the renewable energy share to at least 27% of the total energy consumption. Thirdly, at least 27% improvement in energy efficiency. These set targets are to be reviewed in 2020, with a potential increase of up to 30% (Sdoukopoulos et al., 2019). The EC framed the energy union which covers the following five aspects: energy source diversification and security of energy supply, a higher level of integration of the EU internal energy market, improved energy efficiency, lowered import dependence, economy decarbonisation, and support to research and innovation in low-carbon and clean energy technologies. In context of energy efficiency, the European port sector has an important role to play, as on one hand they are considered as noticeable energy users, and on other hand they also serve as the key areas for energy production from the renewable energy sources (e.g., wind, solar, biomass and waste-based energy). Since European ports affirm that the energy consumption is the second top most important environmental priority, hence for successfully addressing this issue, European port authorities have been working intensively towards setting-up adequate policies, making up targeted action plans and setting management frameworks and systems such as Port Energy Management Plans (PEMP), Green Port Policies and Environmental Management Systems (EMS)(Sdoukopoulos et al., 2019).

4.3 Country or local level – Iran

The number of regulations and policies have been developed for energy efficiency which are applicable in agricultural, industrial and service sectors in Iran. Creating an energy database and consumption statistics, creating a competitive energy market without government intervention, monitoring, reviewing and evaluating policies implemented, facilitating the process of private sector investment in the energy supply chain, supporting and encouraging enhanced productivity in all the energy sectors, enforcing energy management standards are the main policies which were adopted by Iranian government in order to the development of energy efficiency. As development of renewable energies, in addition to increase energy efficiency can decrease the consequences of using fossil fuels. It helps to protect the environment and prevent the waste of health and social expenses so, the government has a positive approach to facilitation of investment in renewable energies especially in the service sectors. Hence, ports are considered as the gateway of a country and providing its services requires energy consumption, so according to port and maritime transport experts of Iran the development and use of renewable energy is necessity for the country and is not a choice.

5 Case Study

5.1 Introduction

Energy resources are one of the fundamental factors and elements of sustainable development. Access to sufficient energy is the main economic factor of industrial societies after manpower. Energy is a basic need for economic development, social welfare, improving the quality of life and security of society. Sustainable energy is defined as the production and consumption of energy in a way that provides human development in the long run in all economic, social, and environmental dimensions, so the sustainable energy supply is a necessity for sustainable development. For these reasons, in recent years, various developed and developing countries are paying attention to renewable energy (solar, wind, geothermal, etc.). The increase of fossil fuel prices, environmental considerations, the security of the energy supply, technological advances and economic justification in some cases are the factors which drive economic sectors including the port and shipping industry to use the renewable energy.

5.2 Renewable energy supply in ports

Ports are distinguished by their geographical density, high energy supply, to meet their needs. Over the past decades, the need to better understand and monitor energy-related activities within the port and public awareness has become increasingly evident. Absorption is seen in the port's innovative technologies such as the power supply at the port or alternative fuels such as LNG and the increase in the growth of renewable energy facilities in port areas, as well as the need to pay more attention to energy issues related to energy management.

This study has attempted to analyse the energy consumption in the container terminal of Bandar Abbas port (as a case study) in Iran and examine twhich are the feasible renewable energies that can be used as an alternative to supply the required power energy in container terminals without interfere in operation in order to reduce the carbon footprint. Regarding the limitation of fossil fuels sources, annual energy consumption growth, and an environmental crisis due to fossil fuel consumption indicates that utilising renewable energies is inevitable in Iran.

5.3 Bandar Abbas port at a Glance

Bandar Abbas Port is located in the south of Iran in the north of Qeshm Island and the strait of Hormuz, at a distance of 15 kilometres west of Bandar Abbas City, and hosts over half of the foreign trade of the country through its transaction with over 80 major ports around the world. It lies at the centre of the International North-South Transit Corridor (INSTC)- one of the most significant transit corridors at the international level- that connects the Persian Gulf and Indian Ocean through Iran to the Caspian Sea, and then through the Russian Federation to Saint Petersburg and northern Europe.

It is located in an excellent geographical position, with access to open seas through the Persian Gulf, connection to international railway network and the Silk Road, using modern equipment and facilities, and proximity to free trade zones in Kish and Qeshm Island and other major ports in the region have turned this port complex into a uniquely strategic asset for the country.

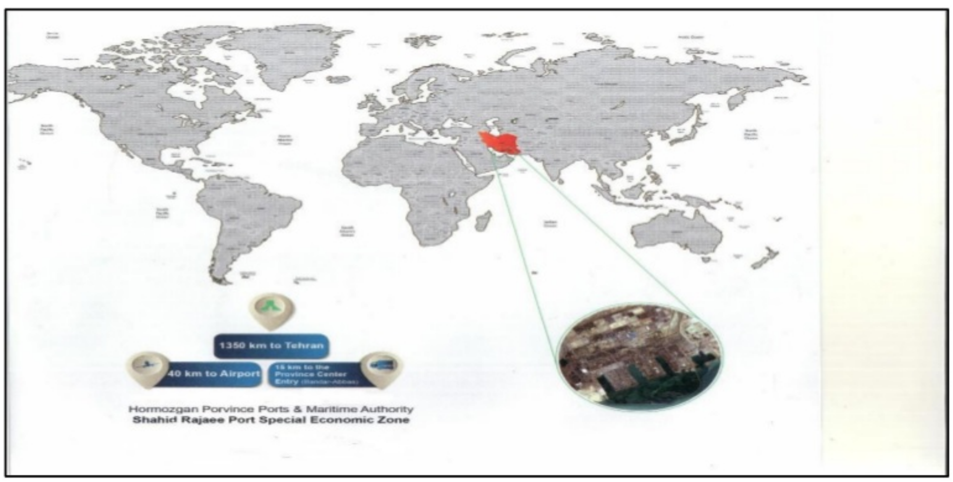
Figure 7

General view of Bandar Abbas city in Iran

Source: https://www.google.se/maps

Figure 8

Location of Bandar Abbas Port



Source: https://www.pmo.ir

The Port Complex, as the largest commercial port in Iran with the capacity of cargo handling of 100 million tons of goods per year, it is the largest and most important port in Iran, which alone accounts for 58% of non-oil goods operations, 43% of petroleum products transportation operations and is responsible for 85% of the container operations at Iranian ports. This port is the largest and most advanced container port in Iran with 18 gantry cranes and 40 wharf posts (Port and maritime Organization, n.d.).

Figure 9

Bandar Abbas sea port plan

Source: https://www.pmo.ir

5.3.1 Container terminal- Bandar Abbas

The container terminal of Bandar Abbas port is capable of berthing large container carriers of the 7th generation, with a draft of 17 meters and capacity of over 140 thousand tons of deadweight, and provides its services using 8 super-post-Panamax gantry cranes. The throughput of terminal had been 2,629,725 and 1,862,593 TEU in 2018 and 2019 respectively (pmo, n.d.).

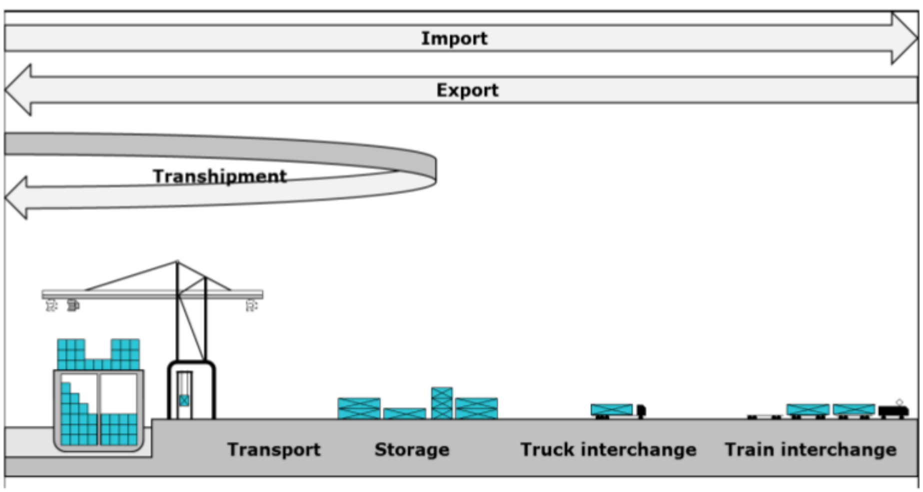
In the near future, some 20 more gantry cranes of the same generation as well as 60 RTG transtainers are planned to be installed in this terminals, which will promote the throughput of the Port from 6 up to 8 million Twenty-Foot Equivalent Units (TEUs) of containers. This terminal employs information technology for management and documentary activities, using the most advanced container management software system (pmo, n.d.).

5.3.2 Terminal Operations and energy consumption pattern

Container terminal provides services for containers according their customs procedures. Import containers are transported from ship to hinterland, and the other option is export which containers are moved from hinterland to ship. Transhipment containers are handled from ship to ship.

Figure 10

Schematic side view of container terminal operations



Source: Adapted from Jahn (2010)

The container terminal includes different parts which consume different types of energy, which are electricity, petrol and diesel. The electricity is provided by the national grid for port activities. The use of fossil fuels for power generation leads to CO_2 emissions. Therefore, finding suitable alternatives for fossil fuels as well as electricity generation can reduce pollution due to terminal activities and increase port sustainability. Table 1 illustrate energy consumers within the terminal.

Table 1

Energy consumers within the container terminal of Bandar Abbas port

Energy consumer / Type of energy	Electricity	Petrol	Diesel
Ship to shore cranes	*		
Buildings	*		
Generators			*
Lightening	*		
Reefer containers	*		
Other port vehicles		*	*

Source: Author, 2020

5.4 Renewable energy potential - Iran

Iran has a total area of 1.648.195 km^2 with about 300 clear sunny days in a year and an average 2200 kw/h solar radiation per square meter. Considering only 1% of the total area with 10% system efficiency for solar energy harness, about 9 million MW h of energy can be obtained in a day (Najafi and et al.,2015).

Iran has also high potential of wind energy, it can be extracted in the country is about 100 GW. Accordingly, if only 56% of the potential of wind and solar energy is used, there is no need for fossil fuels to generate electricity in the country.

Table 2

Estimated capacity of Hormozgan power plant by different types of renewable energy

Type of renewable energy	Biomass(MW)	Wind(MW)	Solar(MW)
Estimated capacity	25	450	3825

Source: (Statistical Report of Renewable Energy in 2018, Renewable Energy and Energy Efficiency Organization of Iran (SATBA))

Proper management of fossil fuels and replacing them with other renewable energy sources properly, has a great effect on reducing greenhouse gases. In addition to the many environmental effects of creating a renewable power plant, the existence of abundant government support and subsidies in Iran (such as the transfer of land for free, a 20-year guaranteed advance purchase at a higher price than the sale price of electricity on the national grid), has been important to moving forward. In the last two decades, given the importance of this issue, the Iranian government has created the Organization for Renewable Energy and Energy Efficiency (SATBA), to manage and plan for the development of renewable energy in Iran. Based on the Solar Atlas of World Bank, Iran is one of the potential destinations for renewable energy and the city of Bandar Abbas is one of the hot and dry regions of Iran, which in this atlas has a relatively good position in the capacity of solar energy production. The climate of Bandar Abbas is affected by semi-desert and desert climate and sometimes its temperature exceeds 51 degrees Celsius. The average annual temperature in this region is about 27 degrees Celsius. The climate of Hormozgan province is characterized by a long hot season and a short cool season (Aghahosseini et al., 2018). According to the report of the Renewable Energy and Energy Efficiency Organization of Iran, Hormozgan Province where the city of Bandar Abbas is located in, and has a high capacity and potential for the development of renewable energy with the priorities of Solar sites, Wind sites and Biomass sites.

Hormozgan province (Bandar Abbas city) is one of the best regions of the country to produce energy, using sunlight. Out of 365 days of the year, 300 days in Hormozgan are sunny, which is a good capacity to use solar energy.

According to geographical capacities, solar and wind energy are two options that can be used for alternative renewable energy sources. Therefore, in this study, the following alternative have been considered to compare with the current situation of power supply in container terminal of Bandar Abbas port.

Scenario 1: utilizing solar energy

Scenario 2: utilizing wind energy

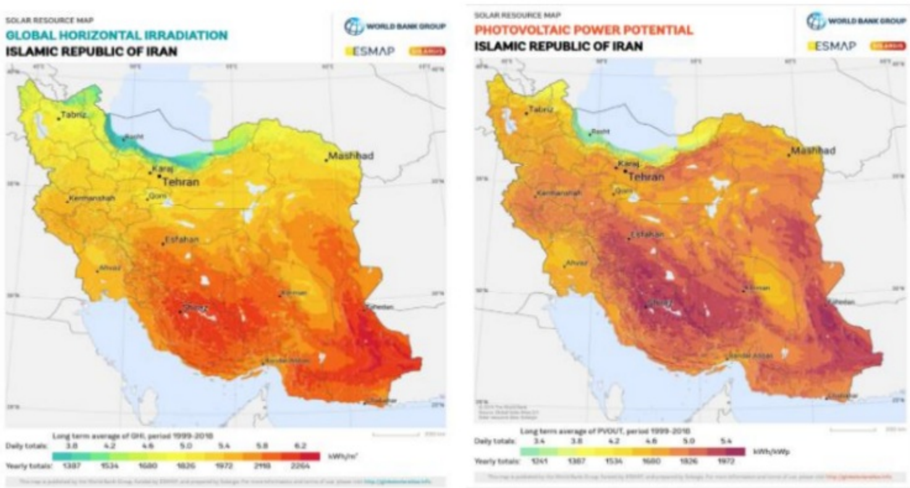
Scenario 3: utilizing a combination of solar and wind energy

5.5 Evaluation criteria

The main issue in energy substitution is determining the most suitable alternative. Among the options available for electricity generation, there is a clear contrast between the economic benefits and the environmental benefits of the options. Fossil fuels are less attractive environmentally.

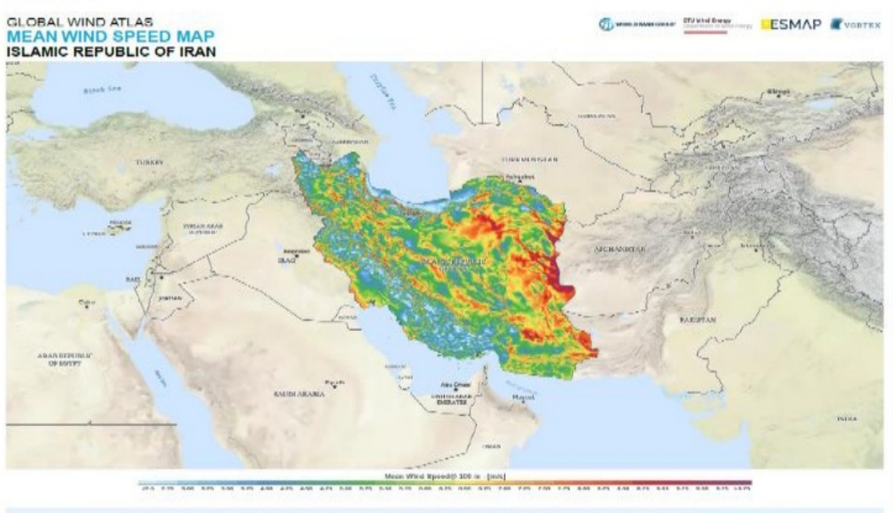
Figure 11

The distribution of the solar energy intensity (kwh/m²/day) in Iran



Source: (IEA,2020)

Figure 12



Wind speed map of Iran

Source: (Global Wind Atlas,2020)

The main issue in energy substitution is determining the most suitable alternative. Although renewable options are environmentally friendly, but in terms of production capacity and stability are not very attractive. Besides, the high investment cost, low maintenance cost of these options make them attractive in the long run. The evaluation of several characteristics of electricity generation systems is required for selecting the suitable option for power generation.

The indicators to compare different options are classified into three main groups:

5.5.1 Physical dimension

A) The sustainability of renewable energy sources

B) The suitability of potential sites associated with each alternative option and the feasibility of the construction of the power plant and geographical position, in this aspect the city of Bandar Abbas has the potential of wind and solar energy.

5.5.2 Environmental dimension

This criterion is not reflected in the price of electricity, but it affects the natural, social, environment and human health. Emission of pollutant gases from burning fossil fuels, damage to migratory birds by wind turbines, radiation from radioactive waste are the examples of these effects.

Due to limitations in this study we addressed one of the most important environmental challenges which is CO_2 emission.

5.5.3 Economic dimension

The unit cost of electricity is determined by calculating the balanced cost. In this method, all capital costs, fuel consumption and, the maintenance costs of the power plant are calculated and finally, the price of each unit of electricity is extracted in cent per kw/h. Due to the importance of economic dimensions, it is discussed in detail in this chapter.

5.5.4 Political, social and other uncontrollable dimension

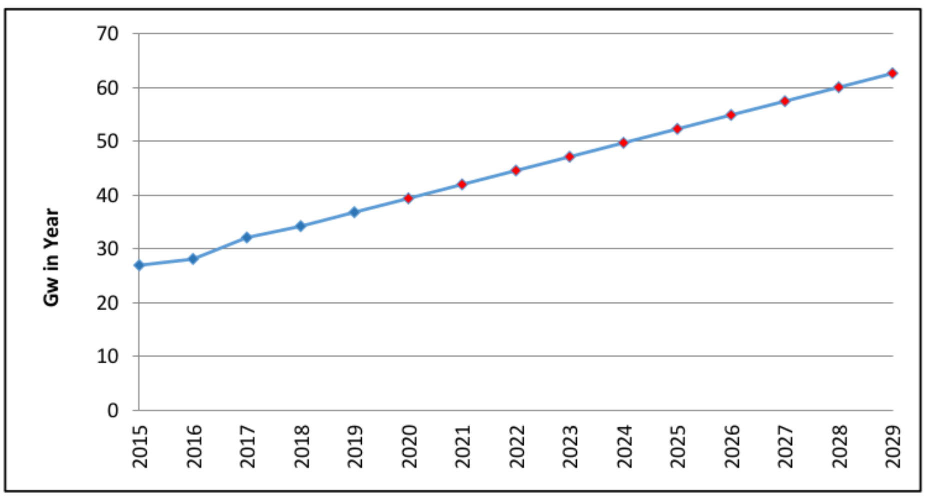
Evaluating the effects of this dimension is so important but it is beyond the scope of this study.

5.6 The quantity of Energy consumption in container terminal

It is required to know the quantity of electricity which is consumed in the container terminal of Bandar Abbas port before the comparison between the energies, so energy consumption data was collected from different parts of the container terminal, total electricity consumption data of the last 5 years was collected and then by applying linear regression, using Excel software, the required electricity in the next 10 years has been predicted. Which is shown in the Figure 13.

Figure 13

Annual electricity usage by Bandar Abbas port - container terminal (2015-2020) and estimation of usage for next decade



Source: (Author,2020)

Due to the growth of the port and the increase in its traffic load, although the current consumption of the port is about 37 GW, due to its increasing trend and the need for long-term planning to provide clean energy required by the port, in this study, the port's future forecast for the next ten years has been considered. Based on this, the total annual electricity consumption is estimated at 62 GW, all financial calculations have been considered based on that.

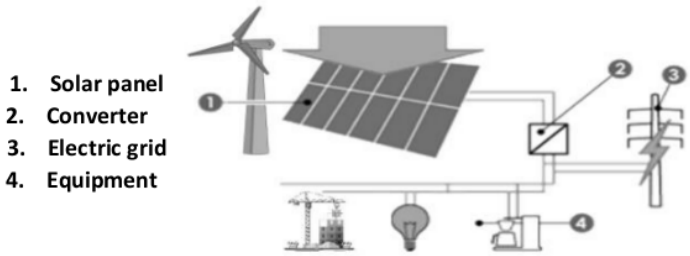
Although, other fuels are also used in the terminal area to provide the services, including diesel those are out of the scope of this study.

5.7 Stability of energy

One of the most important issues of using renewable options including solar and wind is that they are not stable throughout the year, though they are unlimited and free. According to the national policies of Iran and the capabilities of the national electricity network, it is possible to use the network systems, network-connected systems are designed to operate simultaneously and connected to the national grid (Razmjoo, et al.,2017). Converters are one of the main components of these systems which converts DC electricity generated by wind and photovoltaic energy to AC in proportion to the voltage and power of the regional power grid and automatically shuts off power when it is not needed. In general, there is a two-way connection between photovoltaic cells and the transmission network, So that if the DC power generated by these systems is more than the site needs, the surplus is fed to the national grid, and at night and when for some reason it is not possible to use sunlight, the electrical load required by the site will be provided by the national electricity grid, also if the photovoltaic system is out of order due to repairs, the electricity required by the site will be provided through the national electricity network, so, the limitations of resource reliability regarding these options are removed.

Figure 14

Component of systems connected to power grid



Source:(Razmjoo, et al.,2017)

5.8 The economic dimensions of a solar power plant and wind farm to supply electricity to the container terminal

There are two main factors in order to examine the economic dimension which are total capital cost and the cost of electricity consumption. In following these two factors were considered.

The total capital cost includes the predevelopment and consenting, manufacture and purchase, fixing and contracting, operation and maintenance, and retiring and removal costs. Given the basis of the current situation, cost of energy consumption from the national grid was considered and as the continuation of the current situation does not require new investment, therefore, to unify the comparison criteria, in the proposed alternative options (wind and solar), the average cost of electricity (kw/h) calculated by the division of total investment over total production over its lifespan plus operation costs. As an estimation of the capital cost depends on some factors including type of equipment, exact location of the site and also, the distance of the power plant site from the terminal, calculation the cost of transmission equipment, and these cases require separate comprehensive studies and are out of the scope of this study, so to calculate the required investment, the average cost of similar power plants and also other valid studies have been considered. According to International Renewable Energy Agency report (2019), the average cost of electricity in photovoltaic systems (solar) is about

8.5 cents /kw/h and for onshore wind energy is about 5.6 cents/kw/h and offshore wind energy is about 12.7 cents/kw/h (International Renewable Energy Agency, 2018).

Table 3

Global electricity generation cost by different source of energy

Global electricity costs in 2018

	GLOBAL WEIGHTED-AVERAGE COST OF ELECTRICITY (USD/KWH) 2018	COST OF ELECTRICITY: 5TH AND 95TH PERCENTILES (USD/KWH) 2018	CHANGE IN THE COST OF ELECTRICITY 2017-2018
Bioenergy	0.062	0.048-0.243	-14%
Geothermal	0.072	0.060-0.143	-1%
Hydro	0.047	0.030-0.136	-11%
Solar photovoltaics	0.085	0.058-0.219	-13%
Concentrating solar power	0.185	0.109-0.272	-26%
Offshore wind	0.127	0.102-0.198	-1%
Onshore wind	0.056	0.044-0.100	-13%

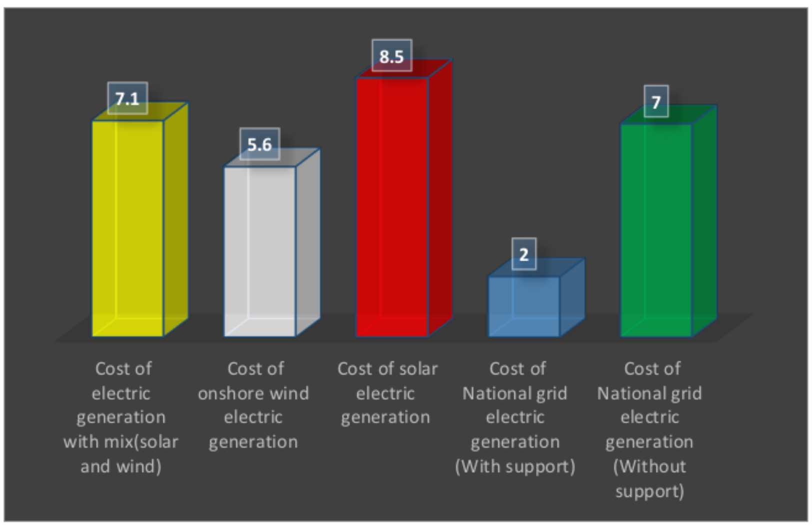
Source: (https://www.irena.org)

As shown in table 3 in recent years, due to the development of technology and increasing the efficiency of equipment, the average cost, especially in the solar equipment sector has fallen sharply so that in just one year from 2017 to 2018 a 13% decrease can be seen in the photovoltaic systems. If this trend continues in the future, it will make investing in this sector more attractive.

Currently, the average cost of electricity from the national grid is 2 c/kw/h in the container terminal, cost of energy has many subsidies in Iran, according to Iranian government reports, about 30 percent of the population receives electricity for free, on average, the government pays about 80 percent of subsidies to the energy sector in Iran. For this reason, the average cost of electricity is less than 1 c/kw/h. This subsidy is more prevalent in the service and industrial sector and less in the public sector of government departments and municipalities. Iranian Ports and Maritime Organization, which is also in charge of the Bandar Abbas container terminal is a governmental organization and has less subsidies and therefore pays about 2 c/kwh. Given that Iran is one of the exporters of electricity in the Middle East, any increase in the country's electricity generation capacity, increases government revenue. For this reason, the price of electricity for terminal container generated by national grid has been calculated according the average export price(c/kwh) of electricity. The export electricity price of Iran to regional countries varies from 5 to 9.5 cents and the average export earnings is about 7 (c/kwh).

Figure 15

Average cost of electric generation from different sources of energy (c/kwh)



Source: (Author, 2020)

According the above mentioned analysis to examine the economic dimension of applying renewable energy to electric generation in container terminal of Bandar Abbas port following assumptions were considered:

- Average cost of solar electric generation – 8.5 c/kwh
- Average cost of onshore wind electric generation – 5.6 c/kwh

- Average cost of electric generation with mix (wind and solar) – 7.1 c/kwh
- Average cost of national grid generation (without support) – 7 c/kwh

5.9 Environmental aspect of power generation

Replacing fossil fuels with clean and renewable energy and protecting the health of the community against pollution from the combustion of fuels and the ability to comply with environmental requirements are the factors that leads to social welfare.

All the power generation systems have environmental impacts. Based on that, the environmental impact, of all the stages of the electricity production chain should be evaluated, including extraction of resources, construction of equipment, transportation of materials, use of electricity, and disposal of waste. Some of the major environmental effects associated with electricity generation including air pollution, greenhouse gas emissions, land use, impact on the ecosystem (fauna and flora) which all have an effect on human health.

In general, in the calculation of the quantity of greenhouse gas emissions and environmental effects of energy production, all stages of the chain from exploration, extraction, and processing of energy resources, extraction of raw materials for technology and infrastructure, production of infrastructure and fuel, production and construction of technology and equipment, operation of power plants, fuel transportation, waste collection, and management should be taken in consideration.

In this section, CO_2 emission from thermal power plants (with fossil fuels), solar power plant and onshore wind power plant has been studied and in the following, the current situation of electricity supply in the container terminal of Bandar Abbas port has been compared with proposed scenarios.

5.9.1 Power plant with fossil fuel

The direct emission of greenhouse gases from fossil fuel power plants depends on the method of operation, type of technology, and the quantity of carbon in the fuel. As higher efficiency technologies are more expensive than low-efficiency plants, and high calorific fuels are more expensive than low calorific fuels, in addition to plant technology, the quantity of fuel carbon plays an important role. It plays a direct role in estimating greenhouse gas emissions. Most of the electricity generated in Iran is produced from gas. The fuels which are used in power plants are natural gas, gasoline, and fuel oil. Natural gas produces the least pollution, and the majority consumption of the country's power sector, i.e. about 88% of natural gas is supplied.

For the current technologies of natural gas power plants, the main emissions are due to the operation of the power plant. Due to the variability of the fuel used and the lifespan of the equipment, the greenhouse gas emissions of this power plant have been calculated around 360-575 kwh / gCO_2eq.

In order to reduce greenhouse gas emissions from these power plants should reduce gas leakage and focus on improving the combustion process, improving power plant efficiency and fuel quality.

5.9.2 Solar energy

The planet receives solar energy in the form of solar radiation, the amount of this radiation is far more than humanity needs. Among renewable energy sources, solar energy is one of the cleanest and most accessible options.

In general, electricity generation from photovoltaic solar panels is efficient and safe. As photovoltaic systems do not burn fossil fuels, they do not pollute the air or produce the toxic greenhouse gases. Regardless of the specific technology, photovoltaic systems emit fewer greenhouse gases than fossil fuel technologies.

5.9.2.1 Photovoltaic power plants

In the case of photovoltaic power plants, unlike fossil fuel systems, most greenhouse gas emissions occur in the upstream life cycle. Exploitation, lifespan, and transportation activities do not have a significant effect on the cumulative emission of greenhouse gases. In this regard, the type of technology used is also effective due to the efficiency, and because of the advancement of technology, the efficiency of the equipment is increasing and its investment cost is drastically decreasing.

These two issues have had a significant impact on improving the performance of photovoltaic power plants in reducing environmental impact and based on surveys, Photovoltaic power plants have a minimum emission of about 34-37 kwh / gCO_2eq throughout the life cycle. Differences in results are due to various factors such as quantity and degree of silicon, unit efficiency, lifespan, radiation conditions, differences in the installation of the type of roof (flat and sloping, etc.).

5.9.3 Wind farm

Wind as a clean and free source of electricity generation is expanding and has become a significant source of power generation worldwide. Its global capacity in 2018 has reached more than 600 GW, the capacity of creating new wind farm varies from year to year and region to region.

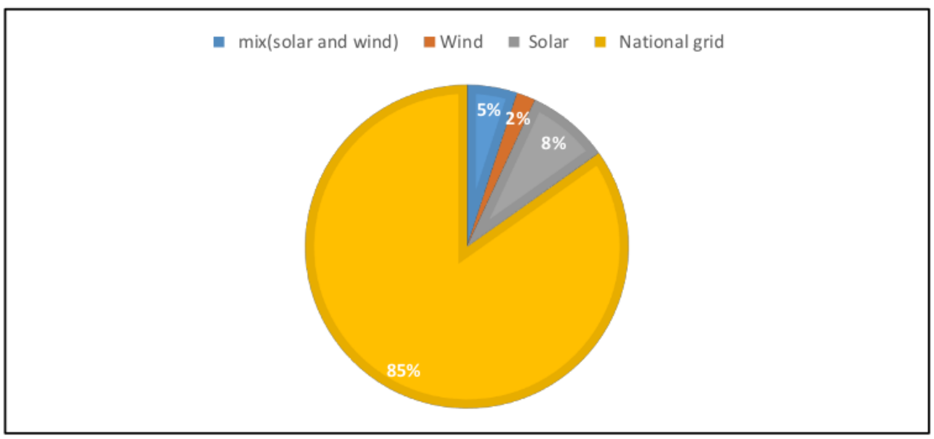
For wind turbines, mainly the greenhouse gas emissions come from turbines. Greenhouse gas emissions from the operation and maintenance, destruction of power plants, transportation of materials, and turbines account for about 10-28% of the cumulative emission of greenhouse gases. The emission of greenhouse gases in the life cycle of wind farms can be very different depending on the location. Estimates are about 8-30 kwh / gCO_2eq for onshore farm and 9-19 kwh / gCO_2eq for offshore turbines.

As mentioned, the source of emission in the life cycle of fossil fuel power plants is related to the operation. However, in the case of the wind and photovoltaic power plants, the construction and production of basic infrastructure cause the emission most in the life cycle of these power plants. In order to study the environmental effects of various power generation technologies, factors such as the effects of construction and operation of the plant on physicochemical, biological, economic, social and cultural should be considered.

Currently, electricity consumption in the container terminal, produces 18000 tons of CO_2 per year, which by changing the sources of energy production and converting it to solar sources, this number reaches about 1750 tons of CO_2 per year and using wind resources to less than 400 tons CO_2 emission per year, and in case of utilizing a combination of solar and wind energy, this amount will be 1070 tons of CO_2 per year.

Figure 16

CO_2 emission of electric generation by different sources of energy



Source: (Author, 2020)

5.10 Scenario Analysis for applying renewable energy

In this case study four scenarios were provided in order to reduce carbon footprint within the container terminal. The options are as follow:

1.Applying solar energy instead of fossil fuels for electric generation in container terminal of Bandar Abbas port

2. Applying wind energy instead of fossil fuels for electric generation in container terminal of Bandar Abbas port

3. Applying mix (solar and wind) energy instead of fossil fuels for electric generation in container terminal of Bandar Abbas port

4. Using the national grid

According the above mentioned analysis to examine the feasibility of applying renewable energy to electric generation in container terminal of Bandar Abbas port and selecting the reasonable option based on three criteria which described in the case study, the following assumptions were considered:

- Unit cost of electric generation regarding each scenario:

➢ Average cost of solar electric generation	8.5 c/kwh
➢ Average cost of onshore wind electric generation	5.6 c/kwh
➢ Average cost of electric generation with mix (wind and solar)	7.1 c/kwh
➢ Average cost of national grid generation (without support)	7 c/kwh

-Annual CO_2 emission at port regarding each scenario:

➢ Electric generation with Solar	1750 t
➢ Electric generation with Wind	400 t
➢ Electric generation with mix	1070 t
➢ Electric generation with National grid	18000 t

Due to the multi criteria nature of the alternatives, to select the ideal option among the suggested scenarios, the TOPSIS technique were applied, which is one of the most widely used for multi criteria decision-making (MCDM) method. This technique is based on the concept that the best alternative has the shortest distance from the ideal solution. As can be seen in Table 4 (decision matrix), we are dealing with the situation of selecting the best option to generate electricity for container terminal out of four scenarios based on three criteria which are cost of electricity, CO_2 emission and stability of energy.

Table 4

Decision matrix

Scenario	Cost of electricity (c/kw/h)	CO_2 emission (t)	Stability of energy
Solar energy	8.5	1750	Good
Onshore wind energy	5.6	400	Good
Mix (Solar and Wind)	7.1	1070	Average
National grid	7	18000	Excellent

Source: (Author, 2020)

The linguistic terms of stability of energy is converted by using the five-point scale, 5 points being given for excellent and 1 point being the lowest and the values substituted in as can be seen in the following table.

Table 5

Decision matrix with quantify criteria

Scenario	Cost of electricity (c/kw/h)	CO_2 emission (t)	Stability of energy
Solar energy	8.5	1750	4
Onshore wind energy	5.6	400	4
Mix (Solar and Wind)	7.1	1070	3
National grid	7	18000	5

Source: (Author, 2020)

In following the vector normalization performed in TOPSIS, and the quantities have been shown in Table 6.

Table 6

Normalized decision matrix

Scenario / Criteria	Cost of electricity	CO_2 emission	Stability of energy
Solar energy	0.58	0.1	0.58
Onshore wind energy	0.38	0.02	0.46
Mix (Solar and Wind)	0.48	0.06	0.35
National grid	0.54	0.99	0.58

Source: (Author, 2020)

Then in order to increase the accuracy of the output, the Shannon entropy technique has been used for weighting the criteria. The weight of each criterion applied in the matrix and can be seen in Table 7.

Table 7

Weighted normalized decision matrix

Scenario / Criteria	Cost of electricity	CO_2 emission	Stability of energy
Type of criteria	-	-	+
Weight of criteria	0.014	0.963	0.023
Solar energy	0.008	0.093	0.013
Onshore wind energy	0.005	0.021	0.011
Mix (solar and Wind)	0.007	0.057	0.008
National grid	0.008	0.957	0.013

Source: (Author, 2020)

In the next step the ideal best value (V_j^+) and the ideal worst value (V_j^-) were calculated for each criterion. For the cost of electricity and CO_2 emission, the minimum value is desired but for the stability of energy the maximum value is desired. The Euclidean distance from ideal best and ideal worst can be seen in Table 8.

Table 8

Euclidean distance from ideal best and ideal worst solution

Criteria	Cost of electricity	CO_2 emission	Stability of energy
Positive V^+_j	0.005	0.021	0.013
Negative V^-_j	0.008	0.957	0.008

Source: (Author, 2020)

Then performance score (P_i) was calculated based on ideal best and ideal worst for each alternative, and in Table 9, according P_i, the alternatives were ranked.

Table 9

Ranking the alternatives

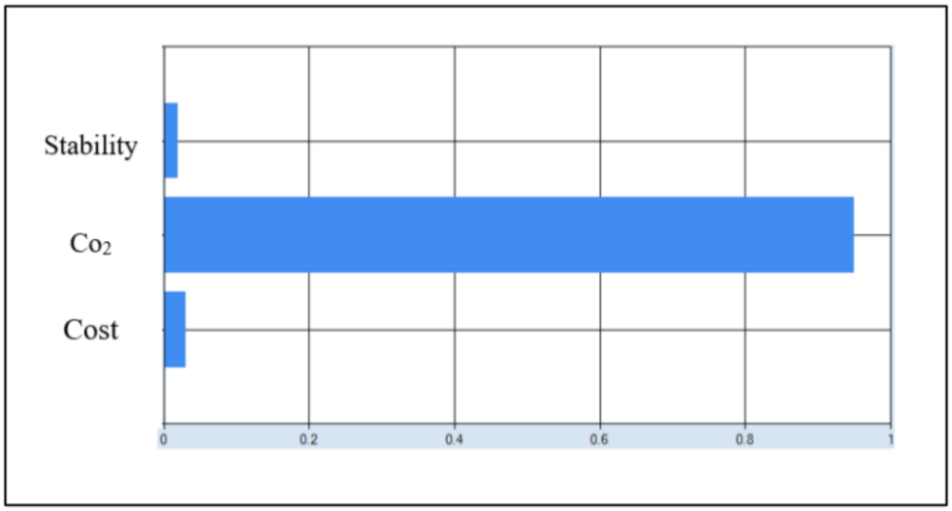
Ranking the alternatives Scenario	Ideal best	Ideal worst	P_i	Rank
Solar energy	0.072	0.864	0.923	3
Onshore wind energy	0.003	0.935	0.997	1
Mix (solar and Wind)	0.036	0.9	0.961	2
National grid	0.935	0.005	0.006	4

Source: (Author, 2020)

Based on the performed calculation, onshore wind energy is the best alternative as it has the maximum value and is the closest option to the positive ideal solution (PIS) and the farthest option from the negative ideal solution (NIS). In other words, the selected option is the one which maximizes the criteria of stability and feasibility and minimizes the cost of electricity and CO_2 emissions.

Figure 17

Comparison of alternatives according the weight



Source: (Author, 2020)

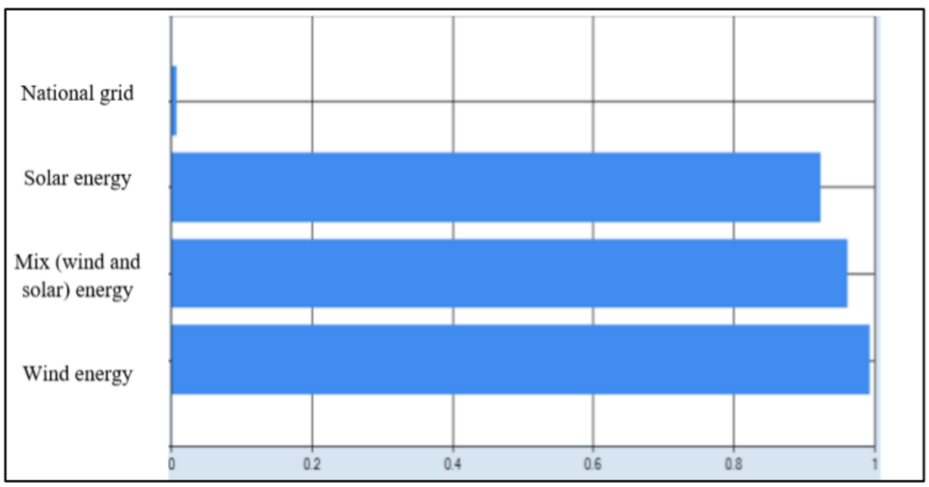
As can be seen in figure 17 among the three criteria, CO_2 is weighted much more than cost and stability and between the alternatives power generation from onshore wind energy creates a minimum amount of CO_2 and for this reason wind energy is the best option according the calculation.

However, due to the fact that in the results of the Shannon entropy weighting technique, the importance of the criteria such as cost and stability is almost ignored, and more than 95% of the decision weight is allocated to CO_2 emission, so practically, this index is set as the main criterion for selection. The proximity of the performance score of the two scenarios of the mix (wind and solar) energy and solar energy to the selected option and the superiority of the solar energy index in two criteria of cost and stability, indicates that if more weight was given to cost and stability indices, solar energy could be ranked higher than the selected option.

Based on obtaining results, the current situation (use of electricity generated from gas thermal power plants-national grid) was far from the ideal situation and was not suitable.

Figure 18

Comparison of alternatives according the performance score (Pi)



Source: (Author, 2020)

5.11 Possible actions to reduce CO_2 emissions in container terminal

Obviously, despite the appropriate effect of renewable energy replacement, this action alone cannot be enough to reduce CO_2 from port activities. Designing environmental management plan and developing port energy management plan are two critical subject that should consider by Iranian port authority to reduce the environmental footprint and increase energy efficiency in the port. Utilizing the successful experiences of leading ports in this context can make the port more sustainable. Meanwhile, the focus on other actions and the implementation of the requirements and environmental standards in the terminal should also be considered.

According to the experts' opinion in Bandar Abbas port which was collected through questionnaires, in addition to using renewable energy, other measures such as electrification of cargo handling and trucks, use of LNG and biofuels for port trucks and cranes, providing incentives for the replacement of older diesel equipment, the use of electric-powered equipment, installation of Onshore Power Supply (OPS), conducting training courses for port tenants and stakeholders to share knowledge and practice minimizing emissions, automated gateway system, idle control on cargo handling equipment, vessel speed reduction in the ports boundary, green berth allocation policies, environmentally differentiated port fees (environmental pricing) should be considered by the port authority to reduce the carbon footprint due to the activities occurring within the port area.

As we know every change in the beginning will face some teething problems. Regarding energy efficiency measures, it will also face problems of effective implementation. Some of those issues are: poor access to information, poor communication channels, limited potential benefits or incentives leading to poor employee involvement, lack of commitment by management due to lack of interest in potential value, and lack of knowledge and understanding of processes and procedures. Barriers to energy efficiency are predicated to hinder investment in cost-effective technological, regulations, and capacity measures that are energy efficient and economically viable (Sorrell et al., 2000). Energy efficiency gaps are the reasons the benefits of cost-effective and energy-efficient technologies are not fully exploited (Jaffe and Steve, 1994).

6 Conclusions and Recommendation

6.1 Conclusion

There is a prompt need for a new paradigm that integrates the continual expansion of human societies and the maintenance of the earth. The importance of energy security and controlling air pollution and greenhouse gas emissions are amongt the priorities which makes the development and utilization of renewable energies inevitable in maritime industry. The development of technology related to renewable energy equipment has significantly reduced the costs and increased its productivity and has accelerated this replacement. This study elaborated on that both economically and environmentally, the use of renewable energy in the production of electricity required by the container terminal of Bandar Abbas port has a higher priority. Based on this, among the four proposed scenarios for generating electric power, the onshore wind turbines option is the suitable alternative to apply to the energy supply within the container terminal of Bandar Abbas port. The results- if applied- will contribute to a reduction of greenhouse gas emissions while at the same time keeping energy costs low and therefore the operational costs down. This contributes to the overall aim of low carbon shipping. Although, along with replacing renewable energies with fossil fuels paying attention to other measures such as implementing an energy management program (ISO50001) as well as updating equipment, machinery and lighting systems in accordance with environmental standards can also have a significant impact on reducing CO_2 emission and other externalities arising from activities in the port area.

It is important to note that the measures which lead to the reduction of CO_2 in ports, in addition to environmental protection, have economic advantages as well, since the governments have to pay a lot for the environmental effects in various areas, including health, utilizing renewable energies which will reduce the cost of negative anthropogenic activities in the shipping industry and will support sustainable ports and sustainable shipping for a sustainable planet-IMO's theme for 2020 (IMO, 2020).

6.2 Recommendation

Conducting further studies on increasing energy efficiency, using the experiences of world leading ports especially in the field of new technologies and the improvement of executive processes, replacement of fuel or technology in the non-electrical parts of the port and the effect of energy subsidies on slowing down the development of renewable energy in Iranian ports can help to complete the result of this research.

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Appendix A

Questionnaire Sent to Research Participants

Study on Iranian Port Authorities' GHG Emissions Reduction Measures

Objective

This questionnaire aims to deduce Iranian Port Authorities perspectives on GHG emissions reduction measures within the port boundaries. The result will be presented to Iranian Port Authorities for Bandar Abbas container terminal as the basis for the development Energy Efficiency Framework (EEF) and "Sustainable Port" Concept for current and planned GHG emissions reductions measures.
The results will also form the basis for recommendations on future port-related policy instruments or measures, which may contribute to the fulfilment of governmental programs and International Maritime Organization's global climate goal.

Questionnaire

For questions, the option 'Plan to use' will be defined as a measure with a current planned implementation strategy and will be used in near future. The option 'Might be use in future' will be defined as a measure that has not been considered in the planned strategy but might be consider in the future strategy plan.
For measures that are not currently in use or planned, please feel free to include any comments, including any challenges or barriers to implementation in the suggestion space provided.

Time

The questionnaire should take approximately 20 minutes to complete. The questionnaire is divided in the following 5 sections:

A. General information
B. Overall GHG emissions in the port area
C. Cargo-handling equipment and on-road vehicles inside the port area
D. Buildings inside the port area
E. Ocean-going ships within the port boundaries
F. Assumption

The study is conducted by the MSc World Maritime student Mrs. Zhila Gordani, for her dissertation.

Section A. General Information

This section includes questions related to your port authority and its main operations.
What is the name of your Port Authority?

Your answer:

What is your job title?

Your answer:

Which are the main vessel types visiting your port? and the Max size of the vessel that can meet the port and port can provide service (Please tick all that apply).

- Containerships ☐
- Dry bulkers ☐
- Tankers ☐
- Ferries ☐
- Cruise vessels ☐
- LNG carriers ☐
- Any other type:

Section B. Overall GHG emissions in the port area

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for the reduction of GHG emissions and air pollutants in the port area.
Development of port environmental policy which is cover energy efficiency including targeted action plan to achieve its set goals
Operational ☐ Plan to use ☐ Might be used in future ☐
Implementing mechanism for systematic periodic monitoring of energy consumption

Operational ☐ Plan to use ☐ Might be used in future ☐

Development of emissions inventories from port activities (establish carbon foot print)

Operational ☐ Plan to use ☐ Might be used in future ☐

Development of air quality monitoring programs for the assessment of the concentration of Co2 and pollutants e.g SO_x, NO_x in the air at port

Operational ☐ Plan to use ☐ Might be used in future ☐

Conduct training courses for port tenants and stakeholders to share knowledge and practice for minimizing emissions

Operational ☐ Plan to use ☐ Might be used in future ☐

Consider of environmental clauses in tenant contracts and provide incentives accordingly

Operational ☐ Plan to use ☐ Might be used in future ☐

Integration between the port and port-city and have cooperation in sustainability measures

Operational ☐ Plan to use ☐ Might be used in future ☐

renewable energy sources usage

Operational ☐ Plan to use ☐ Might be used in future ☐

Implementing Energy Management Plan (EMP) (ISO 50001)

Operational ☐ Plan to use ☐ Might be used in future ☐

Development of Micro grid at the port

Operational ☐ Plan to use ☐ Might be used in future ☐

What other measures would you suggest to reduce the overall GHG emissions in the port area?

Your answer

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for power generation from renewable energy sources.

Installation of solar panels

Operational ☐ Plan to use ☐ Might be used in future ☐

Installation Wind farms

Operational ☐ Plan to use ☐ Might be used in future ☐

Exploitation of wave and tidal power

Operational ☐ Plan to use ☐ Might be used in future ☐

Develop waste to energy system

Operational ☐ Plan to use ☐ Might be used in future ☐

What other measures would you suggest could be helpful for power generation from renewable energy sources?

Your answer

Any additional comments?

Section C. Cargo-handling equipment and on-road vehicles inside the port area

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for the reduction of GHG emissions and air pollutants in the port area from cargo-handling equipment and vehicles inside the area.

Electrification of cargo handling and trucks

Operational ☐ Plan to use ☐ Might be used in future ☐

Use of LNG and biofuels for port trucks and cranes

Operational ☐ Plan to use ☐ Might be used in future ☐

Implementation of incentives for the acceleration of the replacement of older diesel equipment

Operational ☐ Plan to use ☐ Might be used in future ☐

Use electric-powered equipment

Operational ☐ Plan to use ☐ Might be used in future ☐

Use LNG-, LPG-powered equipment

Operational ☐ Plan to use ☐ Might be used in future ☐

Implementation of standardization the environmental requirements for trucks and vehicles e.g. set benchmark for amount of emission for trucks

Operational ☐ Plan to use ☐ Might be used in future ☐

Use automated gateway system

Operational ☐ Plan to use ☐ Might be used in future ☐

Idle control on cargo handling equipment

Operational ☐ Plan to use ☐ Might be used in future ☐

What other measures would you suggest could be helpful in reducing GHG emissions from cargo-handling equipment and on-road vehicles inside the port boundary?

Your answer

Section D. Buildings inside the port boundary

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for the reduction of GHG emissions and air pollutants in the port area from buildings inside the port area.

Improvement of lighting and heating system

Operational ☐ Plan to use ☐ Might be used in future ☐

Use of alternative energy sources

Operational ☐ Plan to use ☐ Might be used in future ☐

Use of LED technology

Operational ☐ Plan to use ☐ Might be used in future ☐

Use energy monitoring system

Operational ☐ Plan to use ☐ Might be used in future ☐

What other measures would you suggest could be helpful in reducing GHG emissions from buildings inside the port boundary?

Your answer

Section E. Ocean-going ships

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for the reduction of GHG emissions and air pollutants in the port area from ocean-going ships.

Vessel speed reduction in port boundary

Operational ☐ Plan to use ☐ Might be used in future ☐

Installation of Onshore Power Supply (OPS)

Operational ☐ Plan to use ☐ Might be used in future ☐

Building of Liquefied Natural Gas (LNG) bunker stations or bunker vessels

Operational ☐ Plan to use ☐ Might be used in future ☐

Implementation of 'Just-In-Time' arrival of vessels

Operational ☐ Plan to use ☐ Might be used in future ☐

Green Berth allocation policies (e.g. 'greener' ships get priority in the allocation of slots)

Operational ☐ Plan to use ☐ Might be used in future ☐

Environmentally differentiated port fees

Operational ☐ Plan to use ☐ Might be used in future ☐

Please identify from the list below the measures that are currently operational, plan to use or might be considered in the future for the reduction of GHG emissions in the port area as the basis for the provision of environmentally differentiated port fees.

Clean Shipping Index

Operational ☐ Plan to use ☐ Might be used in future ☐

Energy Efficiency Design Index (EEDI)

Operational ☐ Plan to use ☐ Might be used in future ☐

Ship Energy Efficiency Management Plan (SEEMP)

Operational ☐ Plan to use ☐ Might be used in future ☐

Environmental Ship Index

Operational ☐ Plan to use ☐ Might be used in future ☐

Any other comments regarding the green ship indexes you currently use, plan to use or would consider in the future?

Your answer

What other measures would you suggest could be helpful in reducing GHG emissions from ocean-going vessels?

Your answer

Section F. Assumption

Assumed that you, as a port manager, decided to choose LNG as an alternative fuel or wind and solar as renewable energy for providing required power of the port. For selecting these alternatives, you will consider three different criteria of:

1-Life cycle CO_2 emission

2- Cost (Capital and maintenance)

3- Particular Matter (as a societal impact)

Please give a grade between 1 and 10 in the following table. The grades must be given based on the importance of the criteria for each alternative.

Criteria / Alternative	LNG	Wind	Solar
Life Cycle CO_2 emission			
Cost			
Particular Matter			