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RESEARCH ARTICLE

STUDYING NEXUS BETWEEN GREEN TECHNOLOGY FUELLING AND INLAND WATER WAYS UPSHOOTS IN DIMINUTING CARBON EMISSIONS AND CONSERVING NON-RENEWABLE FUELS

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ABSTRACT

With the huge increase in global liquid fuels usage leading to global warming due to high pollutant emission; an alarming situation has risen to develop and adopt alternative green technology. This is highly required for transportation sector, one of the major fuel and energy consumers. Inland waterways can be a potent replacement for land and rail transport. IWT dwelling on marine diesel and heavy fuel oil is required to adopt renewable sources of energy to be a competent mode of transportation. Green Technology focusing on alternative sources of fueling in the IWT 's efficient multi modal transport system will be the most certain a breakthrough in the IWT which already shares an advantage on all sections of transport in terms of fuel, cost, carrying capacity etc. This paper highlights various green oriented strategies for improving transportation practices through Inland waterways sustainably. We have explored scope of renewable energy like Solar, Wind, etc. for IWT in India where IWT is carried out only 0.2%. India blessed with huge number of rivers can potentially rely on Inland water transport, and utilization of enormous Solar energy, available wind etc. can massively save fuels and keep environment pollution free. Methodology like Wind and Solar resource assessment, wind energy installations, Wave energy utilization, feasibility study of other alternative sources of fueling based on the climatic, technological sophistications like fuel cells, LNG, etc studied in this paper to harness renewable sources of energy can act as Pole Star for future research and exploration of various technologies in this direction bringing out an innovative set up for the IWT worldwide.

Key Words: Inland Waterways, Green technology, Renewable Energy Sources, Solar, Wind, Resource Assessment, Feasibility Studies.

INTRODUCTION

Inland Waterways

Inland waterways, the cheapest mode of goods transport as per freight costs with high capacity to carry smaller parcels in greater bulk in one go together with less and cheaper fuel, leads to less pollutant emissions. Studies conducted by Inland Waterways Authority of India (IWAI), in paper 'Inland Water Transport – Potential for use in movement of fertilizers' report, 28 January 2010, suggest that not only air pollution, land acquisition and capital required are low but equivalent single unit carrying capacity, energy efficiency and fuel efficiency are sufficiently large. Indian inland waterways sailing vessels mostly use Heavy fuel oil, IDO, MDO etc. Though its emission fraction is too low but still the emission adds to potentials of global warming. Europe with effectiveness of ECA regions has taken bold steps to replace the vessels with more greener fuels like Low sulphur fuel (MGO) , LNG etc. which have relatively very less emissions. Such practices are expected to come into Indian scenario especially with the advent of LNG sector and stricter environmental norms. India with total navigable length of 14,500 kms of inland waterways, moves 45 million tons of cargo (2.5 billion ton-km) annually by IWT contributing to 0.28% of modal share in India.

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While in Europe this same modal share contributes to averagely to about 15% displaying the extent of infrastructure to be developed in India for IWT. Currently India has 5 declared national waterways with least available depths of 2.5m, however NW-1 is being developed for 3m along with some other waterways used for transport of cargo, not declared national waterways. Today Inland Waterways in India are used to transport coal, steel, cement, POL, fertilizers, food grains, stone chips, project cargo, edible oil, ODC, silica sand etc. This paper looks to develop these Indian waterways to be self-sustaining not only in terms of fuels to vessels plying in these waterways but also in development of supporting infrastructure. These infrastructures look forward to development of a zero emission IWT sector with infrastructure stated above. The paper explores the the conceptual development of IWT through renewable sources like wind and solar through concept of "plug, power and navigate" by laying a network of offshore wind and solar farms and powering barges/docks for power generation and thereby using this energy to power ships for distances. The powering barges/docks can be here said to be offshore power sub stations. This alternate source of fuelling infrastructure will revolutionalise the renewable energy industry in the IWT sector and the paper is also suggestive with this concept in IWT as it is self contained and not using even a part of land infrastructure. Apart form the prior concept a series of other new technologies and fuels have been suggested which side with the concept of green technology fuelling with considerably less emissions.

Existing Infrastructure

There are five National Waterways

- NW-1 – Ganga (1620 km)from Allahabad to Haldia
- NW-2 – Brahmaputra (891 km) from Sadiya to Dhubri
- NW-3 – West Coast Canal (205 km) from Kollam to Kottapuram
- NW-4 – Kakinada - Puducherry canals from Bhadrachalam to Rajahmundry with Godavari & Krishna rivers from Wazirabad to Vijaywada (1095 km)
- NW-5 - East Coast Canal from Geonkhali to Charbatia with Brahmani river from Talcher to Dhamra (623 km)
- Total length of 4434 km. declared National waterways

Our case study area is National Waterway-1 that includes river Ganges, Hooghly and Bhagirathi. River Ganges flows through the Northern Plains of India with more than 400 million people around facing amplified air and water pollution due to many reasons including diesel, HFO etc. usage in IWT vessels. Thus arises need for natural or green technology fuelling. Set up of such infrastructures like offshore wind and solar installations can be used for power consumption discharging less toxic into the rivers and more conservation of volume of water due to less evaporation.

Solar Energy

Offshore Solar Platforms

Offshore Solar Platforms use Solar photonic technology which absorb solar photons converting energy to electricity (as in a photovoltaic (PV) cell) or storing part of the energy in a chemical reaction. In this the solar panels are fixed on moored pontoons. The world's first floating photovoltaic system was installed in 2007 by SPG Solar, of Novato, California, on a pond at Far Niente Winery in Napa, U.S.A. The installation has a total capacity of 4MW operational. Floating PV systems have several added advantages like water cooling effect on solar cells, natural reflectivity of water surface, potential reduction in algae growth due to reduced sunlight penetration, and a lower water temperature in areas below the trays alongwith conservation of water reducing evaporation rate. Several designs have also come up in PV technology which includes the Solar Lily pads, hexifloats etc.

Concentrated Photovoltaic Systems

Concentrated PV (CPV) systems, which must track the sun to keep the light focused on the PV cells, use various methods to concentrate sunlight such as mirrors or lenses. The primary advantages of CPV systems are high efficiency, low system cost, and low capital investment to facilitate rapid scale-up. These offer flexibity to operate at lower temperatures to about 25 degree Celsius. In areas of waters in the reservoirs the floating solar panels have their angles of inclination rise and fall with the reservoir water levels. CPV SYSTEMS can capture the reflected sunlight from the water to harness energy in rough waters, with dome shape to trap sunlight reflected from water surface and will have added mechanism to capture the motion produced by waves.

Dish/Engine Systems

Dish/engine systems use mirrored dishes (about 10 times larger than a backyard satellite dish) to focus and concentrate sunlight onto a receiver. The receiver is mounted at the focal point of the dish. To capture the maximum amount of solar energy, the dish assembly tracks the sun across the sky. The receiver is integrated into a high-efficiency "external" combustion engine. The engine has thin tubes containing hydrogen or helium gas that run along the outside of the engine's four piston cylinders and open into the cylinders. As concentrated sunlight falls on the receiver, it heats the gas in the tubes to very high temperatures, which causes hot gas to expand inside the cylinders. The expanding gas drives the pistons.

The pistons turn a crankshaft, which drives an electric generator. The receiver, engine, and generator comprise a single, integrated assembly mounted at the focus of the mirrored dish. Till date these are land based but can be utilized for floating solar platforms too with suitable structural modifications.

Power Tower Systems

Power tower systems, also called central receivers, use many large, flat heliostats (mirrors) to track the sun and focus its rays onto a receiver. As shown below, the receiver sits on top of a tall tower in which concentrated sunlight heats a fluid, such as molten salt, to temperatures as high as 1,050°F. The hot fluid can be used to boil water, which produces steam to run conventional steam turbines and generators. Or, the thermal energy can be effectively stored for hours, if desired, to allow for electricity production during periods of peak demand, even when the sun is not shining. This concept can be too floated offshore using moored floating mirrors, central receivers and floating power system barges consisting steam turbines, substations etc.

Wind Energy

Offshore Wind Farms

It generally involves the installation of wind turbine on a moored, fixed or floating platform on water. Today the world has a whooping capacity of 75GW through off shore wind farms. Large production of power facilitates to reduce energy imports, air pollution and green house gases. Inspite of larger CAPEX involved in the installation of these power platforms there are several advantages associated with them. Considering the offshore wind breezes these are quite strong in the afternoon, especially talking in context of rivers they have a continuous flow of land and river breezes.

These are peak hours for vessels plying on inland waters of India to be located to a loading/unloading facility where they can be powered by the concept studied in paper. Offshore wind turbine shall provide navigational aids in night and proper lighting along the routes due to their high generation capacities. A new concept being developed in Japan is that of Wind Lens which are claimed to be quiet and three times more efficient than any conventional wind turbines; very close to the water surface. These all power units can be integrated to a single floating substation located at the berth through a channel of submarine power lines to power the vessels for their propulsion. Apart from these during non availability of vessels the power generated can be used to green the grid for land based power consumption.

On-Board Renewable Fuelling

Solar Barges

In a study mentioned in "*Sustainable Development of Inland Waterway Transportation In India"* V Janane *et. al.* has considered a solar barge of size: 98mx24mx4m with a capacity of 3000t, usable area 91mx21m, possible number of panels: 1260 have an energy generation capacity of 244kWh costing nearly 9,176,200 for passenger movement in IWT. Solar barges are clean, pollution free, create power while in motion, less maintenance requirement and zero impact on environment. Photovoltaic cells both directly and indirectly absorb sunlight to generate electricity. Every square inch of water which reflects sunlight in all directions adds to overall collection by photovoltaic cells. Power generation of the barge depends on size of barge and number of panels.

Solar Boats/Yachts/Cargo Carriers

These vessels are either partially fuelled by solar power or completely fuelled. For e.g.: Suncat 46 solar yachts having hull width 6m length 14m have a total capacity of 6KW from assembled solar modules. However others like Turanor Planet Solar (overall length 31m,537 square metre solar panel) having power capacity of 24KW is fuelled by solar energy. The segment has found limited or partial power generation in the cargo carrying vessels. For e.g.: Auriga Leader (60213 GT) equipped with 328 solar power cells can generate 40KW to cover 0.2% of the ship's energy consumption for propulsion.

Turbosail/ Rotor Ships

These ships basically use Magnus effect for wind propulsion, consisting of an airfoil vertical and grossly ovoidal tube, with a mobile flap which improves the separation between the intrados and extrados. Operations have suggested savings of fuel by 25% For e.g.: E-Ship-1.Further this concept is being used to mitigate global warming. The ships would spray seawater into the air to enhance cloud reflectivity. Such similar concepts can be used to fuel inland vessels and reduce use of HFO/MDO to certain percentage.

Fuel Cell

Hydrogen fuel cells are the new promising technologies for fuelling inland waters, which are, not only green fuel but have greater efficiencies (60%), greater operating times (a journey of 4 to 6 hrs gives 12 to 18 KWh power) and less refueling (once a month). Also the energy stored is 2.8 times greater than gasoline per unit mass. It involves development of green hydrogen generation and refueling infrastructure throughout inland waterway. Onboard hydrogen producing systems are to be developed.

Liquified Natural Gas (LNG)

Liquified Natural Gas is a greener fuel with least emissions in most of the ships across the world. LNG infrastructures like LNG Terminals, bunker barges etc. have promoted its use. LNG is cheaper fuel than fuel oil and a necessity in ECA regions. Recent development of dual fuel engines by Wartsila has also encouraged the ships to undergo retrofits for LNG. Also the volume reduction it offers gives more energy in a less volume. A study has been presented in this paper in context of the route studied in report for LNG infrastructure to be developed for fuelling the inland vessels in these regions.

ECO Trimaran

A new concept boat/yacht for carrying passengers is being developed with a combination of wind, solar and wave energy on board to fuel the yacht. The yacht has roof covered with solar cells, two H-type rotors and floats for wave energy and smooth navigation and less drag.

Wired Electric Boats

The concept is not highly practiced due to its limitations but can act as an excellent fuelling if developed, similar to metros. One or two wires fixed over the water and the boat can make contact with them to draw electrical current. In case of a single wire the electrical circuit has to be closed by the water itself, giving rise to a larger resistance and corrosion of the electrodes.

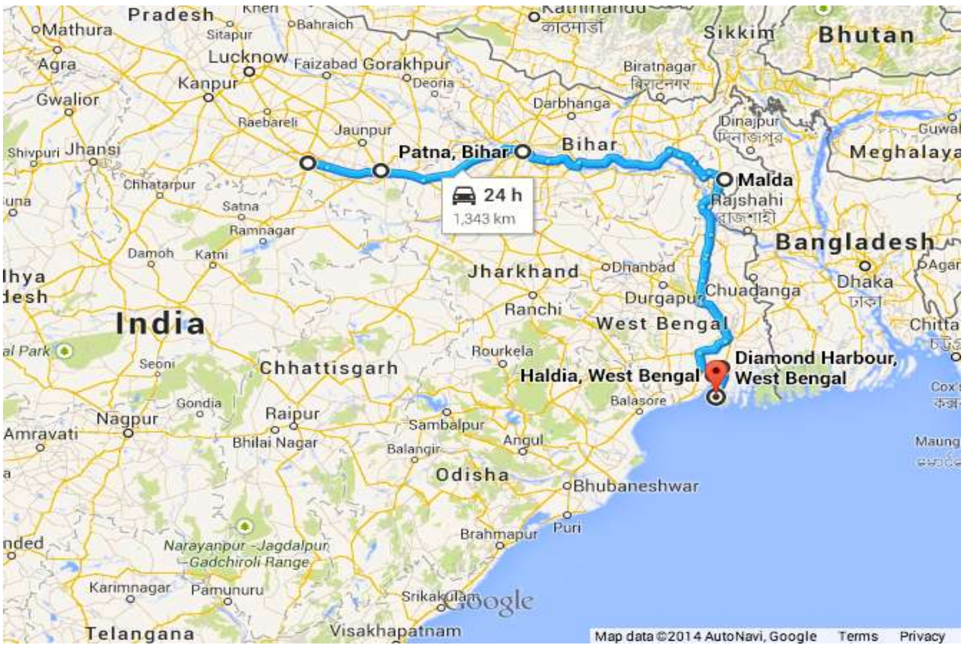


Fig.1. Map of Route to be studied, Source: Map data 2014, AutoNAvi, Google Maps

In case of two wires no electrical current has to be sent through the water, but the twin wires, which cause a short-circuit whenever they come into contact with each other, complicate the construction. Naturally the boat has to stay close to the wire and therefore it is limited in its maneuverability. For ferries and on narrow canals this is no problem.

MATERIALS AND METHODS

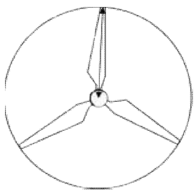
Case Study: Wind Power Assesment Report

Based on the above data, calculations to estimate power generated by a standard dimension of wind turbine is done. 10 such wind turbines are to be installed on the places studied whose power outputs are indicated giving a total capacity of 162.2 MW. The wind power generated is calculated by the

formula:

$$P_{available} = 1/2 x \rho x A x v^3$$

$$A = \pi r$$



Where ρ is density of medium

A is the swept area of turbine
And v is the wind velocity
The wind assessment report is as follows:

The cities/locations taken into consideration for the wind resource assessment in the above route were as follows:

- Sagar Islands
- Haldia
- DiamondHarbour (Kolkata)
- Malda
- Allahabad
- Varanasi

Table 1. Wind Assessment Report

WIND TURBINE PARTICULARS:		
NO. OF WIND TURBINE	1	
BLADE LENGTH	80	M
Cp(Power Coefficient)	0.4	
Area	20096	m2
Density of Air	1.225	kg/m3

Conclusion

The single cities with their offshore wind power capacities will act as substation for the vessel travelling in this route. The vessel depending on its engine capacity shall travel for a particular distance, after which it may charge itself during the time of loading/unloading at the berth via a power barge/dock which will be the substation of all the combined systems in that place for its further voyage.

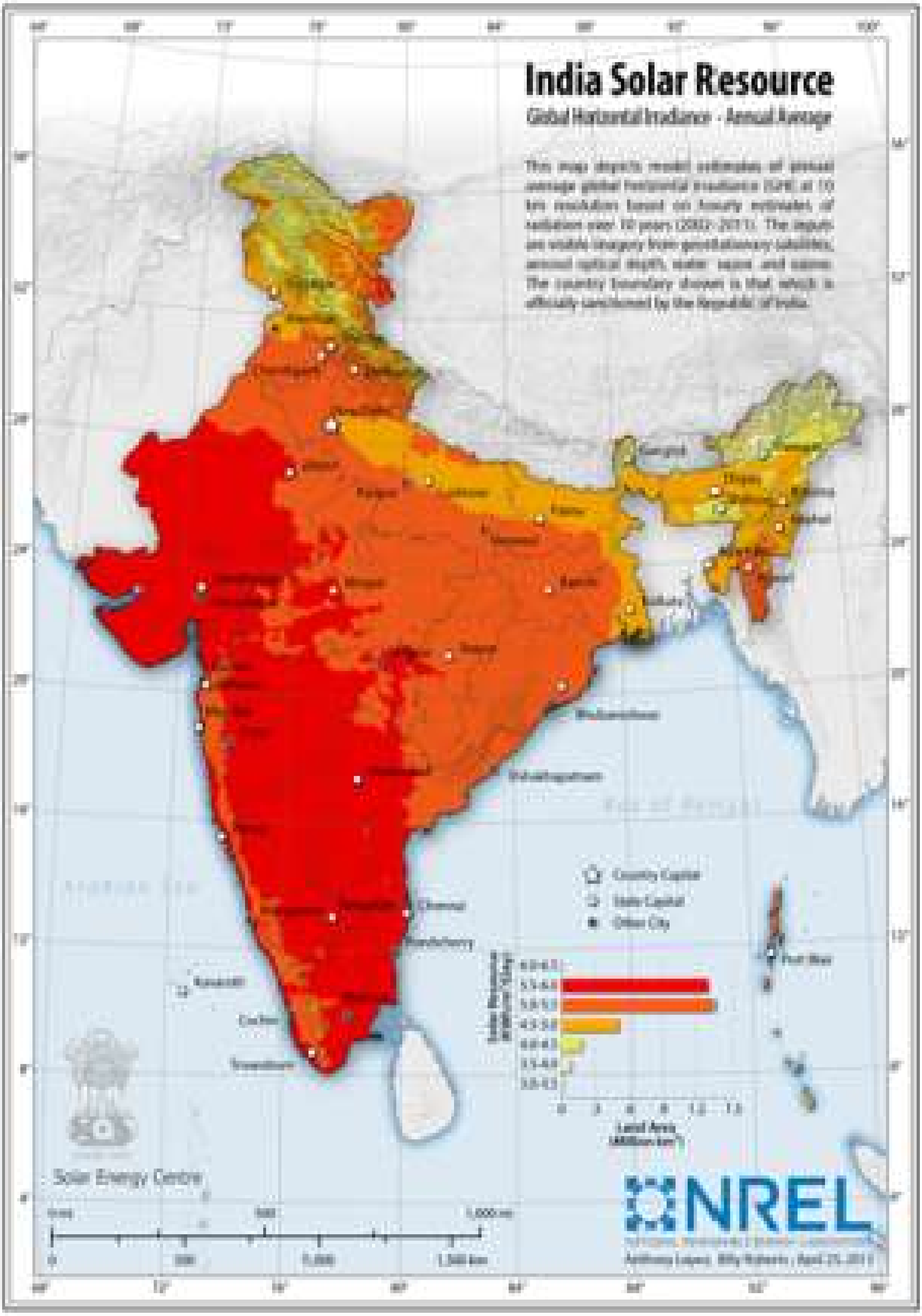
Case Study : Solar Power Assesment Report

The solar assessment report studies the aspects required in order to maximize solar resource for the region. These mainly include sustained clear skies, absence of Haze (atmospheric turbidity), dry atmosphere, minimal air mass (minimum latitude) and high site elevation (minimum pressure).To study them Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) maps of the region have been provided. The temperature table is suggestive to clear skies sustained in a year along with the inference that most months are warm with high temperature.

The climatic condition data place wise are as follows

The above data clearly suggests due to different climate the sustained clear skies are not present overall times presenting a hindrance to maximization solar power harness. The number of rainy days is clearly suggestive to the above point. Apart from this however the temperature readings stand for favorable sunlight throughout the year indicating a favorable solar availability. The next section studies the subject of DNI and GHI to study the feasibility of installation of offshore solar platforms in these regions.

	WIND SPEEDS						
	0830 HRS	1730 HRS	0830 hrs	1730 hrs	AVERAGE SPEED	WIND POWER GENERATED	TOTAL WIND POWER GENERATED
PLACE	km/hr	km/hr	m/sec	m/sec	m/sec	MW	(MW)
SAGAR ISLAND	19	18.3	5.28	5.08	5.18	0.7	6.8
HALDIA	13.6	16.3	3.78	4.53	4.15	0.4	3.5
DIAMOND HARBOUR	13.6	14	3.78	3.89	3.83	0.3	2.8
MALDA	12.3	10.6	3.42	2.94	3.18	0.2	1.6
ALLAHABAD	18.3	16.3	5.08	4.53	4.81	0.5	5.5
VARANASI	19	18.3	5.28	5.08	5.18	0.7	6.8
CAPACITY						2.7	
TOTAL NO. OF WIND TURBINES(EACH PLACE WITH 10)						60	
TOTAL CAPACITY						162.2	


India Solar Resource
Global Horizontal Irradiance - Annual Average
Country Capital
State Capital
Other City
Land Area
Solar Energy Centre
NREL

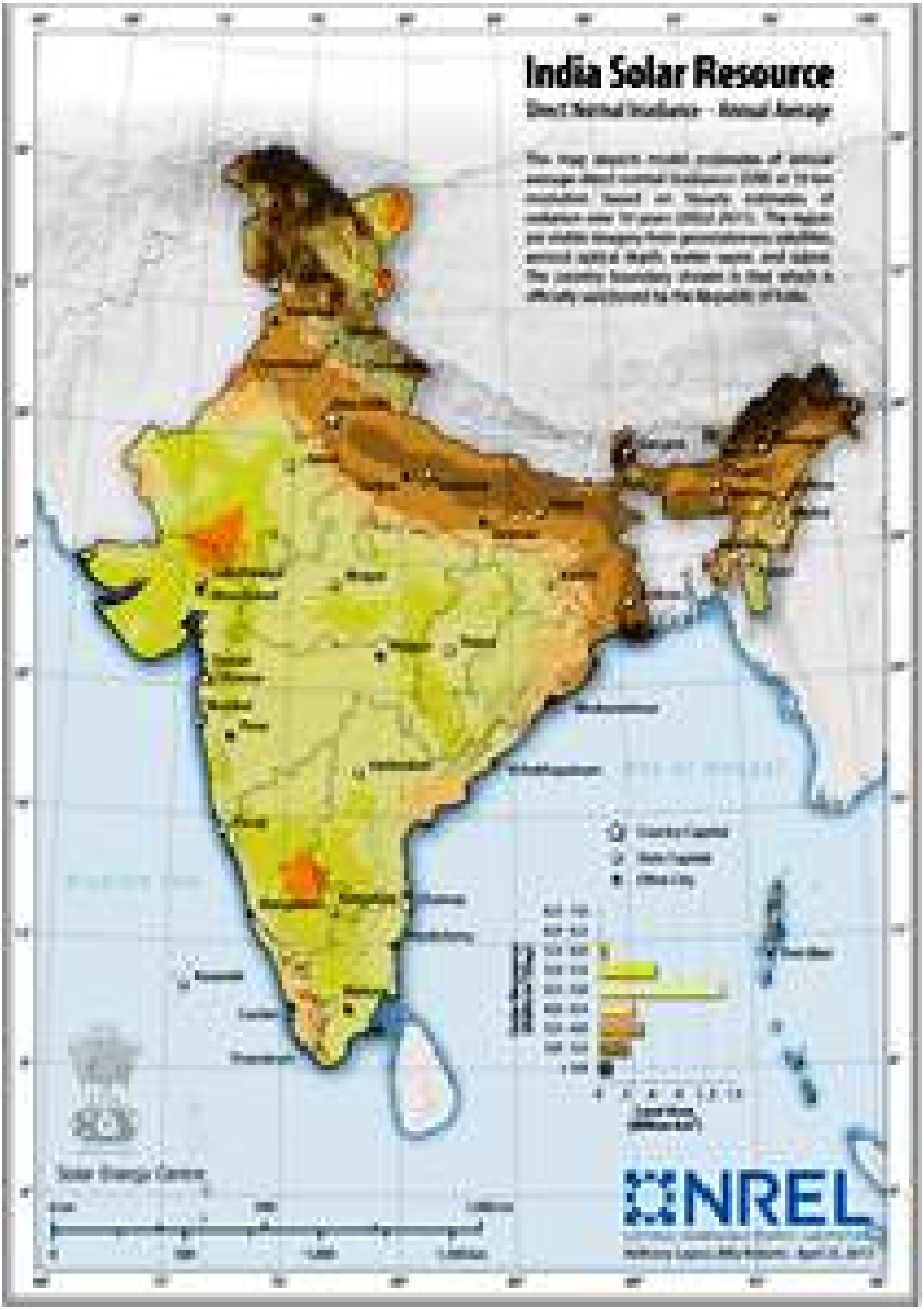


Fig.2. ***Source*: National Renewable Energy Laboratory**

Fig.3. *Source*:Earth, EOS Project Science Office, NASA Goddard Space Flight Center

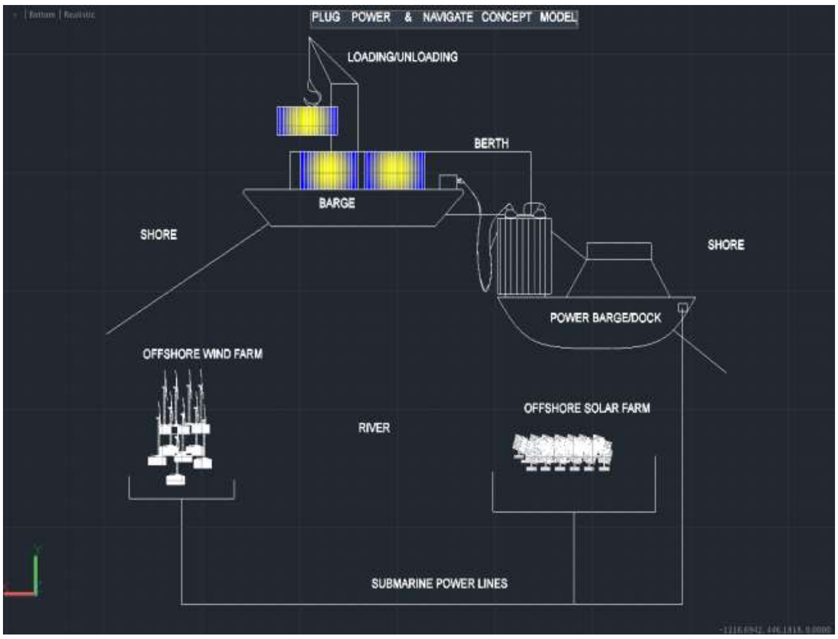


Fig. 4. Plug Power & Navigate Concept Model (AutoCad View)

Table 2. Solar Assesment Report

Global formula :	E = A * r * H * PR	
E = Energy (kWh)	4 104	kWh/an
A = Total solar panel Area (m^2)	20	m^2
r = solar panel yield (%)	15%	
H = Annual average irradiation on tilted panels (shadings not included)*	1825	kWh/m^2.an
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75	
Total power of the system	3.0	kWp
As per previous map		
H = Annual average irradiation on tilted panels (shadings not included)* /day	5.0	kWh/m^2.day
Since the region is at boundary of two GHI regions therefore average value is taken		
Losses details (depend of site, technology, and sizing of the system)		
– Inverter losses (6% to 15 %)	8%	
– Température losses (5% to 15%)	8%	
– DC cables losses (1 to 3 %)	2%	
– AC cables losses (1 to 3 %)	2%	
– Shadings 0 % to 40% (depends of site)	3%	
– Losses weak irradiation 3% yo 7%	3%	
– Losses due to dust, snow... (2%)	2%	
– Other Losses	0%	

Table 3. LNG Cost Analysis

NW-1 CITIES	DISTANCE(KM)	LANDING COST(Rs/kg)	FREIGHT COST(Rs./kg)	END CONSUMER COST(Rs./kg)
HALDIA	0	43.57	0	43.57
KOLKATA	100	43.57	0.23	43.80
FARAKKA	550	43.57	1.25	44.82
BHAGALPUR	717	43.57	1.63	45.20
PATNA	1010	43.57	2.29	45.86
VARANASI	1270	43.57	2.88	46.45

Table 4. Comparison of Emissions by differentmodes

VESSELS	FUEL OIL USAGE (kt)	LNG USAGE (kt)	CO2(FROM F.O.)	CO2(from LNG)	CO2(FROM SOLAR)	CO2(FROM WIND)
SAILING BOATS	1.8	1.4	5.8	4.4	0	0
MOTOR BOATS	186	147.9	588.2	441.2	0	0
PERSONAL WATERCRAFT	34.6	27.5	108.4	81.3	0	0
INLAND GOODS CARRYING VESSELS	2.3	1.8	7.5	5.6	0	0
VESSELS	**FUEL OIL USAGE (kt)**	**LNG USAGE (kt)**	**N20(FROM F.O.)**	**N20(from LNG)**	**N20(FROM SOLAR)**	**N20(FROM WIND)**
SAILING BOATS	1.8	1.4	5.8	0.3	0	0
MOTOR BOATS	186	147.9	588.2	29.4	0	0
PERSONAL WATERCRAFT	34.6	27.5	108.4	5.4	0	0
INLAND GOODS CARRYING VESSELS	2.3	1.8	7.5	0.4	0	0

Table 5. 1 Way Trip NW-1 Plug Power Navigate Concept Feasibility Report

ASSUMPTION	ENGINE	POWER(KW)	QUANTITY(twin screw)	SPEED(km/hr)	TOTAL POWER(KW)
		248	2	9	496

Route						AVERAGE ENERGY CONCEPT[55029.32MJ]	TIME EFFICIENT CONCEPT
Origin	Destination	DISTANCE(KM)	POWER BARGE/DOCK CAPACITY(MW)	ENERGY REQUIRED(MJ)	MINIMUM TIME FOR CHARGING(min)*	ALLOWABLE TIME(min)	ALLOWABLE TIME(min)
Sagar Island	Haldia	89	7.7	17639.8	38.18	120	164.84
Haldia	Diamond Harbor	64	4.4	12684.8	48.04	208.2	208.2
Diamond Harbor	Malda	414	3.7	82054.8	369.6	247.8	240
Malda	Varanasi	700	2.5	138740	924.6	366.6	240
Varanasi	Allahabad	171	7.7	73982.2	51.9	120	120

The maps below represent DNI and GHI on a per day basis which will help to estimate the combined solar capacity. rce: National Renewable Energy Laboratory The above map of daily DNI suggests presence of favourable sun belt but on the contarary also reflects presence of aerosol causing haziness which sometimes act as huge setback to solar power harness in the studied region as studies suggest of 5% less solar power, a drop of 0.86 watt per square inch due to this effect. However the power can be harnessed during clear skies. The satellite map shown below gives an idea of the haziness present, however with the advent of monsoon and shift of air mass this blanket of smoke is dispersed. The effect is due to the result of presence of a large amount of coal and other industries leading to this dimming effect.

Earth, EOS Project Science Office, NASA Goddard Space Flight Center

The black part presents the haziness present leading to the above mentioned dimming

The above data after keeping in view the other factors to hinder solar power harness the map of Global Horizontal Irradiance is used to get the estimate of a 20 square metre solar cell which generates a capacity of 3KW.However the total number of such panels for a single place can be expected to be 300 which gives power output of single berthing station to be 0.9 MW and number of places for such offshore solar installations if taken are 8(as per the climatic data table) then it comes to a total of 7.2 MW. This added power capacity of each berthing station will pool the power to the power docks/barges to harness the renewable energy for the fuelling of ships.

Case Study : Liquified Natural Gas (LNG)

The LNG is also coming up as a very promising fuel for the near future. In a study conducted by DNV.GL on *"Future of LNG Breakbulk Shipping in India"* this region in particular has been studied to develop the break bulk infrastructure in India through the concept of shallow draft self propelled barges, the same concept can be developed for bunkering techniques in these regions. In the study landing cost at various terminals were indicated as follows:

Here the landing cost is based on KOCHI LNG Terminal price, which stands way out of other bunker fuels in terms of pricing and freight feasibilities. Here the LNG bunker barges, Small LNG terminal storage tanks along the places indicated in above table can be used to store fuel for LNG fuelling of vessels .The concept barge supplying the above facilities the LNG has a capacity of 923.28 tonnes (L:75m B:16m Freight Cost: Rs. 2.27/ton-km) and follows a concept of parcel dropping to these regions in ISO CONTAINERS which can be used to develop the bunkering facilities in these regions. This all will also lead to a more greener environment in this route which has been studied. The bunkering facilities like bunker barges, trailers and storage tanks can be provided with the LNG bunker via transshipment of the break bulk LNG. The concept above uses LNG container barges due to its less freight than any other mode in the region. The above reading clearly suggest that the solar and wind energy stand out ahead in front of even LNG with zero emissions. The next section clearly explains the infrastructure that needs to be developed for harnessing the solar and wind energy for "plug, power and navigate" concept of this paper. Therefore to upshoot in dimuniting carbon emission, the above data clearly justifies this concept on an environmental stand. The power consumption by these vessels for its fuelling has been explained in detail in the next section. Points so as to how make this system totally sustainable are explained in next section. The above table explains the energy management for fuelling the vessel (L:75m B:15m Dispalcement: 3000 tonnes Draft:2.5m) on the route studied in the paper. An average of 55029.32 MJ is required between different stations for traversing these stations. The power barge/dock capacity is the combined capacity of offshore solar and wind farms. However adding more number of berthing stations and power barges substation can bring down the average energy requirement. The time efficient concept involves a total of 16.21 hrs for charging the battery for travelling through the voyage but if more stations are added this power charging time can be reduced to a value of loading/unloading time. However the average time for charging at one station is near to 2 hrs 44 min. Also the capacitor required to store this energy is a restriction but this can be overcome by adding more intermediate power barges. This study will make the whole infrastructure of IWT to be self reliant by not depending on other fuels thereby adding a share to protection of non renewable source. This will subsequently add to the eco-green factor to this sector of Inland Waterway Transport. In all the concept studied has a very promising future and can be applied in different parts of the world.

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