University Journal of Research
ISSN (Online) 2455-1724

Grid-Tied Solar Photovoltaic Systems For Electric Vehicle Charging In Gujarat: A Comprehensive Study

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Abstract

The global industrial landscape, including the Indian renewable energy sector, anticipates a substantial surge in photovoltaic system deployments within the national power grid. This growth aligns with the concurrent expansion of battery electric vehicles (BEVs) and rooftop photovoltaic (PV) power generation—both advancing rapidly to mitigate carbon emissions in India's transportation and energy sectors. This study presents an empirical analysis of rooftop solar PV installations in Gujarat, with a focus on the feeder networks in Palanpur city. Through comparative examination, it identifies strategies to alleviate grid strain caused by EV charging loads during evening hours. The study particularly explores the potential of installing EV charging stations on feeders in urban areas characterized by high penetration of rooftop SPV installations. The approach not only highlights the synergy between renewable energy and sustainable transportation but also emphasizes the importance of localized solutions to optimize grid efficiency and promote clean energy adoption at the community level.

Keywords:- Rooftop SPV, EV charging, Feeder-specific analysis, Gujarat charging infrastructure.

1. Introduction

Across various sectors, governmental bodies are implementing incentives aimed at encouraging the adoption of clean and efficient technologies. These measures are strategically designed to align with carbon emission reduction goals and foster a more eco-friendly and sustainable future. The anticipated dominance of electric vehicles (EVs) in the near future necessitates strategic utility planning for the installation of EV charging stations, both at residential and commercial levels. While commercial charging infrastructure is still in early stages of development, residential EV charging remains a primary option. However, the widespread adoption of residential EV charging is expected to significantly increase the load on substation transformers. This heightened demand also leads to secondary voltage fluctuations and imbalances in three-phase power supply (Singh, 2021). Efficient integration of renewable energy—particularly grid-tied solar photovoltaic (PV) systems—is essential for managing EV charging loads. While these strategies can prevent the overloading of distribution components, many overlook considerations related to customer convenience (NITI Aayog, 2023; Zeb, 2023). This research aims to address pollution challenges in highly polluted Indian cities such as Ahmedabad, where transportation is a major contributor to emissions. Although EVs present a viable solution, the lack of commercial charging infrastructure remains a significant barrier. Fortunately, several government initiatives have led to the installation of rooftop solar PV systems on government buildings. This study proposes an approach that optimizes the use of grid-tied rooftop solar PV systems for EV charging, leveraging daytime solar energy to reduce dependence on the grid (Alanazi, 2023; Haghani, 2023).

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I. Comparative Literature Survey

Title	Method	Key Findings	Gaps
Grid Impact of EVs Powered by PV (Vulfovich, 2022)	load flow analysis using ETAP	Solar-powered EVs improve feeder voltage profile	No dynamic control of load and generation
AI-Based Smart Charging of EVs (Anand, 2021)	AI-based charging scheduling	Reduce grid strain	Not tested on real data
Grid-Connected PV-Based Microgrid as Charging Infrastructure for EV Load (Chowdary, 2022)	HOMER and MATLAB	Shown operation under varying solar conditions	Future integration with AI/ML
Power Converter Topologies for Grid-Tied Solar PV Powered EVs (Esfahani, 2022)	Comprehensive review	Analyzed various converter topologies for PV-EV-grid systems	focuses on theoretical comparisons
Integration of Solar-Based Charging Station in Power Distribution Network and Charging Scheduling of EVs (Elbarbary, 2023)	Techno-economic analysis and simulation	Shown cost reduction through solar-based EV charging integration	specific regional analyzed
Solar Powered EV Charging Station with Integrated Battery Storage System (Shukla, 2024)	Simulated using PVsyst	Off grid PV system with battery for EV	Focused on single location

2. EV Charging Load Profile

The daily load profile for a 30 kWh electric vehicle (EV) with a 20% state of charge (SOC), charged using a 240V, 16A (3.5 kW) Level-1 EV charger in a residential setting, shows a noticeable increase in evening peak loads. This surge significantly contributes to the overall stress on the local distribution network (Prajapati, 2019; Sachan, 2022). To simulate typical user behaviour, it is assumed that EV owners initiate charging upon returning home at 17:00 hours. Using a 3.5 kW charger to replenish approximately 24 kWh, the charging session concludes by midnight. This typical charging pattern is depicted in Figure 1, which compares residential electricity consumption with and without EV charging.

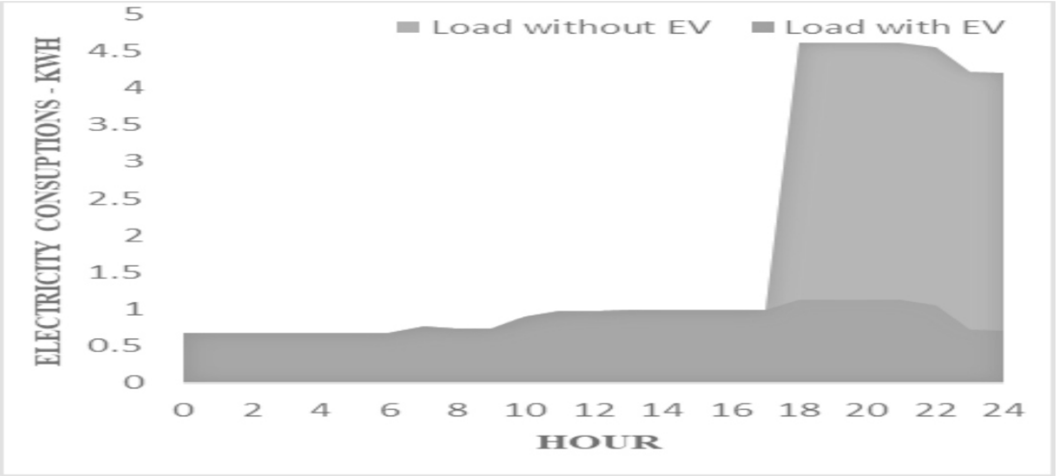

Figure 1. Residential load profile with and without EV charging.

As part of a state-led initiative, rooftop solar panels have been mandated for government buildings. This study proposes the installation of rooftop solar PV systems at such locations where EVs are typically parked during daylight hours. This enables charging during periods of peak solar availability, allowing EVs to be charged without placing additional burden on the grid (Gulzar, 2024; Elavarasan, 2020). Electric vehicle (EV) charger specifications vary across different charging levels—Level 1, Level 2, and Level 3—and these configurations differ significantly between countries. In India, for residential charging, Level 1 alternating current (AC) chargers with a power rating of 3.5 kW are the most commonly used. These chargers typically require 7–8 hours to fully recharge a 30 kWh EV battery (Abraham, 2021; Ahmad & Bilal, 2023).

The technical specifications of EV chargers adopted in India are summarized in Table 1.

Table 1 EV Charging Station Specifications in India

No	Charging Station Type	Voltage (V)	Power (kW)	Compatible Vehicle Types
1	Level 1 (AC)	240	<=3.5	4w, 3w, 2w
2	Level 1 (DC)	>=48	<=15	4w, 3w, 2w
3	Level 2 (AC)	380-400	<=22	4w, 3w, 2w
4	Level 3 (AC)	200-1000	4.3 to 22	4w
5	Level 3 (DC)	200-1000	Up to 400	4w

These levels cater to a variety of vehicle types, from two-wheelers to heavy-duty four-wheelers. The increasing variety of chargers reflects India's evolving EV ecosystem and highlights the need for compatibility and standardization across different EV segments (Ahmad & Bilal, 2023).

III. Electricity Scenario of Gujarat

In 2010, the Jawaharlal Nehru National Solar Mission (JNNSM) set a national target aimed at fostering the growth of India's solar industry. The target was to achieve 20 GW of grid-connected solar power by the year 2022 (Karthik, 2019). In 2015, India revised its solar targets, aiming for 100 GW (Gigawatt) of solar power capacity by 2022, which included 40 GW from rooftop solar installations. Despite not meeting this ambitious goal, utility-scale solar capacity reached 70.1 GW by June 2023. However, rooftop solar installations fell significantly short, reaching only 8.8 GW by the end of 2022. Subsequently, in 2022, India increased its renewable energy targets to 500 GW by 2030, with solar generation accounting for 280 GW of this total (Ministry of New and Renewable Energy, 2023 ;Raina, 2019). In October 2023, the Government of Gujarat introduced the Gujarat Renewable Energy Policy - 2023, delineating the state's renewable energy strategies effective until 2028. Under this policy, Gujarat aims to achieve a renewable energy capacity of 100 GW by 2030, encompassing various sources such as solar (ground-mounted, rooftop, floating, canal top), wind (rooftop, utility-scale), and hybrid projects combining both generation types (Elavarasan, 2020 ;Karthik, 2019)

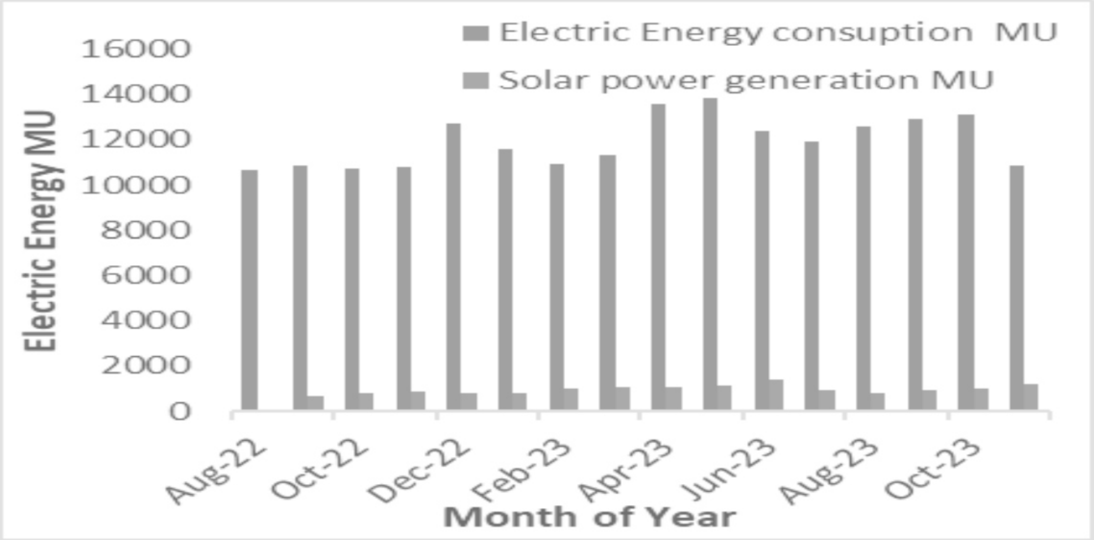

Figure 2. Electricity demand and solar power generation in Gujarat (Aug 2022–Nov 2023).

The Government of Gujarat has initiated significant efforts to promote the development of renewable energy sources within the state. As evidenced in Figure 2, solar power generation exhibited fluctuations from 650 MU (Million Units) to a peak of 1400 MU during the period of Aug-2022 to Nov-2023. Concurrently, electricity demand in the state ranged from 10600 MU to a maximum of 13800 MU for the same period. As illustrated in Figure 3, the percentage of electricity demand and solar power generation from August 2022 to November 2023 indicates that solar power generation reaches its peak in June and decreases to a minimum in August, attributed to the rainy season (Central Electricity Authority, 2022). 1 Million Units (MU) = 1,000,000 kilowatt-hours (kWh).

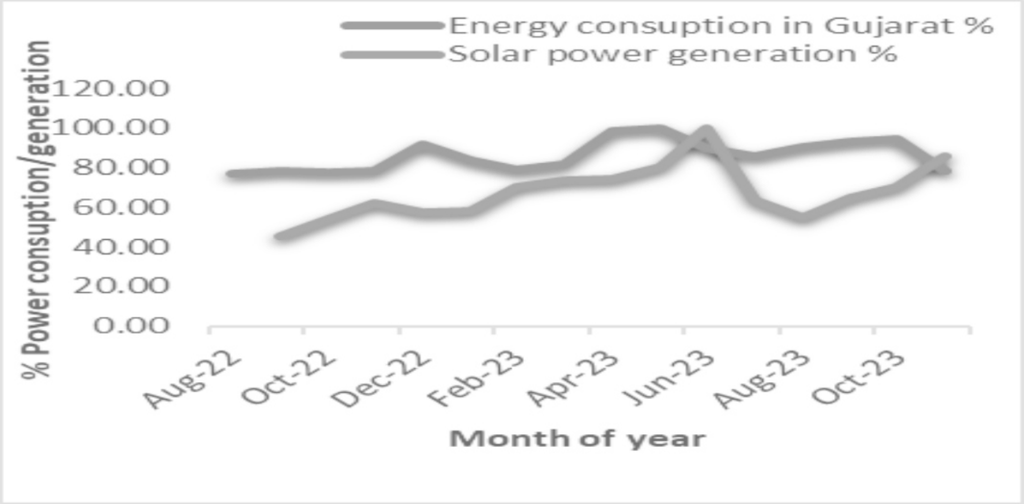

Figure 3. Percentage of solar PV generation relative to electricity demand in Gujarat.

Table 2. Statistics for solar PV Electricity Generation and Demand Gujarat

Statistics	Value	Year
Installed PV Capacity	7.8 GW	Nov, 2022
Total Installed Capacity	48 GW	Nov, 2022
Total Electric energy demand	10,721 MU	2021-22
Share of PV on total Electricity Generation	10.48 MU	2021-22

As of August 2022, Gujarat boasts the highest installed capacity of 1.92 GW rooftop solar among all states in India as shown in Table 3. Additionally, it holds the second-highest installed capacity in utility-scale solar projects nationwide (Ghose, 2019).

Table 3. Solar PV installed capacity of Gujarat in year 2022

Type	Capacity (GW)
Ground	5.91
Rooftop	1.92
Hybrid	00
Off Grid	0.04
Total	7.87 (14%)

IV. Development of EV charging infra in Gujarat:

In the realm of EV charging infrastructure, governance is largely contingent on ownership and usage dynamics. Broadly categorized, EV charging infrastructure falls into three main classifications: public, semi-public, and private. Private charging pertains to the dedicated charging facilities utilized for personal EVs or EV fleets, typically owned by a single entity. These charging stations are commonly situated in independent homes or designated parking spots within apartment complexes. (NITI Aayog, 2021 ;Sachan, 2022). Semi-public charging involves shared charging facilities accessible to a limited group of EV users. These charging stations are commonly found in locations such as apartment complexes, office campuses, gated communities, shopping malls, hospitals, universities, and government buildings. Public charging infrastructure is designed to be accessible to all EV users. These charging stations are typically located in public parking lots, on-street parking spaces, charging plazas, petrol pumps, highways, and metro stations (Kishore, 2022 ;Rather, 2022).

Table 4. Details of EV charging stations in Gujarat year 2022-23.

Types	Number of stations
No of EV Charging Stations	368
No of Heavy-Duty Vehicles (E-bus etc.) charging stations	96

The expansion of the EV ecosystem in Gujarat extends beyond vehicle manufacturing. The state has experienced a notable rise in the proliferation of public charging stations.as shown in table 4 (Ministry of New and Renewable Energy, 2023).

Table 5. Electricity consumption details of EV charging stations in Gujarat year 2022-23.

Types of charging station	Units
Electricity Consumed in EV Charging Stations (in KWh)	409030
Electricity Consumed in Heavy Duty Vehicles (E-bus etc.) charging stations (in KWh)	24694128
Total Electricity Consumed (in MU)	25.106

In the EV domain, the typical battery capacity varies based on the vehicle type. For instance, two-wheelers generally have a battery capacity of around 2 kWh, while three-wheelers typically possess a 5-kWh capacity. Four-wheeler EVs commonly feature battery capacities of approximately 30 kWh and more. In the case of electric buses, their battery capacity exceeds 150 kWh. Notably, heavy-duty vehicle charging stations exhibit significantly high electricity demand. The total electricity demand for EV charging in the year 2022-23 amounted to 25 MU shown in table 5 (Central Electricity Authority, 2022 ;Gode, 2021).

V. Potential of rooftop PV for EV charging: Case study of Palanpur city

The greenhouse gas emissions of Battery Electric Vehicles (BEVs) are notably lower compared to Internal Combustion Engine Vehicles (ICEVs) reliant on fossil fuels. However, the extent of emissions reduction hinges significantly on the technologies employed for power generation. A comprehensive analysis of average CO2 emissions across various scenarios underscores the substantial potential inherent in coupling rooftop PV generation with BEVs for individual mobility decarbonization. Notably, the impact of home-charging could be mitigated if BEVs utilize available solar PV power during daytime at workplaces or charging stations, potentially resulting in near-full charge upon returning home (Martin, 2022 ;Jacob, 2022 ;Irfan, 2023). Such practices not only promote renewable energy adoption for EV charging but also alleviate strain on the grid during evening and nighttime hours, when EV charging demand typically peaks. This integration effectively contributes to enhancing the environmental friendliness of EVs while easing the burden on the grid during periods of heightened demand (Jacob, 2021).

Table 6. Summary of Rooftop SPV consumers connected on distribution network.

Feeder Labels	Number of Customer	Installed Solar Load KW
Feeder - 1	6	18.38
Feeder –2	242	879.78
Feeder –3	110	384.97
Feeder –4	85	327.61
Feeder –5	1	2.6
Feeder –6	46	148.13
Feeder –7	6	17.94
Feeder –8	55	191.55
Feeder –9	134	492.25
Feeder –10	2	5.94
Feeder –11	27	100.93
Feeder –12	125	405.21
Feeder –13	18	153.3
Feeder – 14	73	304.97
Feeder – 15	125	459.96
Feeder – 16	32	134.57
Feeder – 17	2	5.94

Feeder Labels	Number of Customer	Installed Solar Load KW
Feeder – 18	1	2.99
Feeder – 19	2	10
Feeder –20	26	199.37
Feeder –21	66	271.59
Feeder –22	39	281.3
Feeder –23	180	664.9
Feeder –24	282	1076.65
Feeder –25	7	48.96
Feeder - 26	127	448.51
Grand Total	**1819**	**7038.3**

The provided data in table 6 presents an overview of the situation in Palanpur city, encompassing 1819 consumers with an average rooftop PV size of 3 kW. The rooftop PV systems are integrated into the distribution network, with a cumulative installed solar PV capacity of 7038 kW (Fokui, 2021).

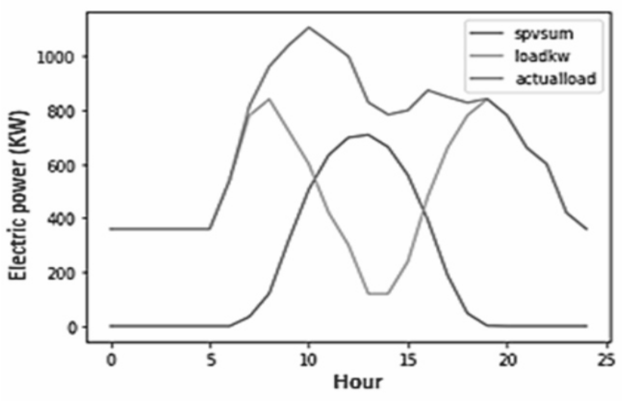

Figure 4. Load Curve of Feeder 24 with Actual and Net load profile with solar rooftop system.

The depicted feeder load profile of November 2022 showcases in figure 4, illustrates the feeder load profile for November 2022, highlighting variations in feeder load, solar PV power generation, and the resulting actual load. It is evident that by incorporating charging stations along the feeder and integrating them with a robust grid-tied solar PV plant, solar power utilization for EV charging during daylight hours becomes feasible. Furthermore, by implementing a dynamic pricing model where EV charging rates are lower during the daytime—when solar PV generation is high and the load on the feeder is low—solar energy utilization can be further optimized. This model can be made more effective by assigning feeder-specific charging rates based on the solar power generation capability and real-time loading conditions of each feeder. (Reiman, 2019). This strategic deployment not only optimizes the utilization of solar energy but also facilitates the efficient charging of EVs. Consequently, Palanpur city stands to leverage its solar potential effectively, contributing to sustainable energy practices and reducing reliance on conventional grid sources during peak demand periods (Ahmad, 2021).

The proposed EV charging infrastructure algorithm can be scaled to larger cities by integrating real grid data analytics, optimizing renewable energy utilization, and implementing adaptive load management strategies. Collaboration with distribution companies (DISCOMs) will ensure seamless grid integration, while dynamic pricing models aligned with PV generation and feeder load conditions will enhance economic feasibility. Smart IoT-based monitoring and AI-driven predictive analytics can further optimize charging schedules, reducing grid stress and maximizing renewable energy consumption. Additionally, partnerships with municipal authorities and private stakeholders will facilitate widespread deployment at high-demand locations. Regulatory support and consumer incentives will drive adoption, ensuring that the algorithm remains adaptable across diverse urban energy ecosystems, ultimately improving grid stability and accelerating EV adoption at scale. As India accelerates its transition toward sustainable mobility, the integration of electric vehicles (EVs) charging load with renewable energy sources presents a significant opportunity for economic, environmental, and energy security benefits.

a) Economic Benefit for EV Owners (Fortum India, 2024).

Annual Cost Savings for EV Owners

- Fixed rate charging: Rs 60,000/year

  (Rs 20/kWh × 30 kWh × 100 charges)

- Dynamic rate charging: Rs 45,000/year

  (Rs 15/kWh × 30 kWh × 100 charges)

EV owners benefit from ₹15,000 in annual savings and a 25% reduction in charging costs, making EV adoption more affordable.

b) Annual Grid Cost Savings per MW Load Shift

Shifting EV charging load to periods of high renewable energy (RE) generation or off-peak hours reduces strain on the grid, leading to significant cost savings.

- During peak hours, Distribution companies procure expensive power from thermal or peaking plants (Rs 6– Rs10/kWh) (NITI Aayog, 2024).
- Shifting 1 MW load for 5 hours daily (1,825 MWh annually) to RE-based charging at Rs3– Rs5/kWh instead of peak pricing results in savings Annual Grid Cost Savings per MW Load Shift around Rs. 3 – 5 crore.

National Economic Benefits

- India spends 100+ billion dollar annually on crude oil imports.
- India's EV30@30 target aims for 30% EV penetration by 2030, leading to 80-100 lakh EVs on the road. Large-scale, Feeder specific, PV generation-based EV load management system, could save approx. Rs.1-2 lakh crore in fuel import costs by 2030 (Soman, 2020).
- Feeder specific, PV generation-based EV load management system aligns with India's 500 GW renewable energy target by 2030. Encourages foreign investment in clean mobility & smart grids (TERI, 2024).

CONCLUSION:

Gujarat currently leads the nation with the highest installed capacity of rooftop solar, standing at an impressive 1.92 GW. The state is actively pursuing new initiatives to further expand rooftop installations across different cities, indicating a promising trajectory for increased solar adoption in the future. With this anticipated growth, the daytime output of solar power on individual feeders is expected to rise in the coming years. Through strategic integration and effective management of EV charging slot timings, it becomes feasible to harness solar energy for EV charging at the distribution level. This approach not only optimizes the utilization of solar resources but also aligns with Gujarat's commitment to sustainable energy practices. By leveraging solar power for EV charging, the state can enhance its renewable energy utilization while simultaneously promoting eco-friendly transportation solutions.

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University Journal of Research
ISSN (Online) 2455-1724

Deep Sea Mining, Opportunities for India and Urgency to Act

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Abstract

With the dawn of the Information age demand for Rare Earth Elements has shot up multifold. While China has managed to maintain a monopolistic grip on global production and supply of Rare Earth Elements, other major players such as the USA, Europe, Japan and India are now waking up. The aim of this paper is to underline the national importance of having secure supply of Rare Earth Elements and the opportunities that are available via Deep Sea Mining operations in production of such elements. Also various tools and techniques used for such operations are discussed.

Keywords:- Rare Earth Metals, Polymetallic Nodules, Sulfides Nodules, Cobalt Crust, United Nations Convention on the Law of the Sea (UNCLOS), International Seabed Authority (ISA), Belt and Road Initiative (BRI), Remote Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), Hybrid underwater robotic Vehicle (HURVs).

1. Introduction

As Electronics, Microchips and Computers have found their uses in all aspects of life the uses of Rare Earth Metals have increased exponentially, Metals such as Lanthanum, Neodymium, Europium, Erbium, Samarium have become very important and highly sought after. Other Metals such as Cobalt, Nickel, Copper, Molybdenum and Yttrium are also used in similar applications. All such Metals are available at the seabed and can be extracted for civilian as well as military uses.

Deposits at the seabed.

Various deposits are available at the sea bed but the major deposits are as follows.

- Polymetallic Nodules: Often these nodules are also referred as ferromanganese nodules or manganese nodules. They are formed at the seabed by deposition of iron and manganese hydroxides layer by layer on top of each other over a core. They mostly contain silicates and iron and manganese oxides. These nodules are found in deep sea as well as shallow waters and they contain an abundance of Nickel, copper and Manganese along with other Rare Earth Elements. Their formation takes millions of years with an approximate growth rate of 1 – 3 mm per million years. (Toro et al., 2020) (Joseph, 2017)
- Sulfides Nodules: Hydrothermal Vents at the sea bed result in deposition of sulfides of various Metals such as silver, gold, copper, manganese, cobalt, and zinc. Active or extinct Hydrothermal Vents at the sea bed have a large collection of such nodules around them. They are formed due to the interaction of sea water with hot volcanic rocks. Such hydrothermal vents are mostly found at the depth of 1000 to 4000 meters in the deep sea. (WOR, 2014)
- Cobalt Crust: As the name suggests this is a hard layer of rock deposit with abundance of cobalt in it. These are formed very slowly over millions of years with formation rate as low as 1 to 5 mm per million years. They are formed on exposed rock surfaces and unlike nodules they are rigidly attached to the surface making it more difficult to mine them. They also act as shelter to various marine animals and their mining is going to result in loss of various marine eco-systems. Such crusts are mostly found at the depth of 600 mtrs to 7000 mtrs at the seabed. (WOR, 2014)

Elements available at the sea bed and their applications

Following is a comprehensive list of Elements that can be mined via deep sea mining along with their civilian as well military application.

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Table 1: Elements available at the sea bed and their applications.

Sl No.	Element	Symbol	Application	
			Civilian	Military
1	Lithium	Li	Battery, Power storage	Power source for various Automated weapons
2	Aluminum	Al	Aerospace Industry, Conductors, Heat Exchangers	Fuselage of various Aircrafts
3	Barium	Be	Fireworks, glass manufacturing, drilling fluids	Radar-absorbing materials
4	Bismuth	Bi	Cosmetics, alloys and fire extinguishers	Production of bullets, Cold fusion reactor.
5	Boron	B	Rocket Fuel Igniter	Various missiles and weapon systems
6	Cadmium	Cd	Rechargeable batteries, pigments, corrosion-resistant plating	Ammunition
7	Calcium	Ca	Medical, Steel Production	NA
8	Chromium	Cr	Stainless Steel, Alloy Steel with Creep Resistance	High temperature Alloys, Turbines, Jet Engines
9	Cobalt	Co	High temperature alloys, High-speed steel, Li-ion Batteries, Permanent Magnet	High temperature Alloys, Turbines, Jet Engines
10	Copper	Cu	Conductor, Heat Exchangers	Power Generation and transmission
11	Gallium	Ga	Semiconductors, LEDs, solar panels	High-temperature solders, thermal imaging devices
12	Gold	Au	Jewelry, electronics, dentistry, monetary standard	Electronic components, connectors, coatings for equipment
13	Iridium	Ir	Spark plugs, fountain pen nibs, platinum alloys	Electronic components, missile guidance systems
14	Iron	Fe	Ship Building, Construction	Ship Building
15	Lanthanum	La	Lighting, catalysts, optical glasses	Electronic components, alloys
16	Lead	Pb	Lead Acid Batteries, weights for lifting, cable sheathing	Radiation protection, ammunition
17	Magnesium	Mg	Production of mobile phones, laptops etc	Production of various Human interface devices
18	Manganese	Mn	Fertilizers, Ceramics, High temperature alloys	High temperature Alloys, Turbines, Jet Engines
19	Mercury	Hg	Thermometers, Barometers, Manometers, Dental amalgams, fluorescent lighting	Liquid mirror telescope, Explosives and Munitions
20	Molybdenum	Mo	Alloying agent, lubricants, catalysts	Armor plating, aircraft parts, gun barrels
21	Nickel	Ni	Low temperature Steel, Wear resistance steel alloys, Permanent Magnet	Cryogenic Fuel Tanks, Cryogenic rocket motors

Sl No.	Element	Symbol	Application	
			Civilian	Military
22	Palladium	Pd	Catalytic converters, electronics, jewelry	Electronic components, catalysts
23	Phosphorus	P	Fertilizers, Safety Matches, Steel Production	Flares, LED panels
24	Scandium	Sc	SunLight lamps, Aerospace	Airplane Fuselage, Russian MiG Fuselage
25	Silicon	Si	Medicinal, various plasticware, Microchips, Solar Panels	Various microchips.
26	Silver	Ag	Jewelry, photography, electronics, bactericide	Electronic components, mirrors, medical equipment
27	Sodium	Na	Soaps, Paper, Detergents, Ceramics, Medicinal	NA
28	Strontium	Sr	Fireworks, pyrotechnics, medical imaging	Flares, tracer ammunition, radiation detection devices
29	Tellurium	Te	Alloys, solar panels, electronic components	Electronic devices, sensors
30	Thallium	Ti	Photocells, manufacturing of glass, rat and ant poison	Infrared optics, Bio weapons.
31	Tin	Sn	Soldering alloys, food packaging, corrosion-resistant plating	Ammunition
32	Titanium	Ti	Aerospace Industry, High temperature application	Airplane Fuselage, SR 71 Black bird
33	Tungsten	W	Light bulb filaments, high-speed tools, armor-piercing ammunition	Armor-piercing ammunition, armor plating, electronic components
34	Vanadium	V	Steel Alloys, Nuclear Reactors	Nuclear Propulsion for Aircraft Carrier
35	Ytterbium	Yb	Laser technologies, medical treatments, materials	Laser-based targeting, communication systems
36	Yttrium	Y	LED phosphors, ceramics, lasers	Missile guidance systems, aircraft engines
37	Zinc	Zn	Galvanizing, batteries, alloys, cosmetics	ammunition, brass casings
38	Zirconium	Zr	Nuclear reactors, ceramics, alloys	Armor plating, nuclear submarines, missile components

As evident from Table 1 a large number of these metals have Military applications, also they are essential for production, storage and utilization of renewable power.

Regulations Concerning Deep Sea Mining

There is no single convention so far that is dedicated to control of exploration and exploitation of Deep-Sea resources at high seas, but as of now the mining operation is controlled as per following.

- United Nations Convention on the Law of the Sea (UNCLOS): Under this convention the maritime boundaries of a nation are determined. Also, the Maritime boundaries of a nation are further divided into various zones as shown in the figure below. (UNCLOS, 1982)

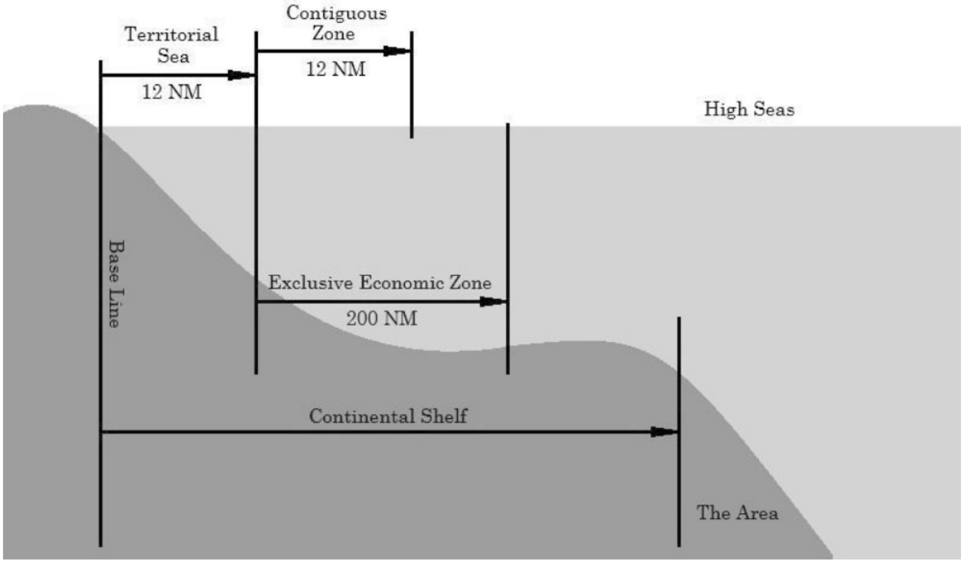

Figure 1: Maritime Zones as per UNCLOS

1. Territorial Sea

Up to 12 nautical miles from the baseline. All Foreign Flag Vessels have the right to innocent passage. Coastal states may exercise jurisdiction if the vessel is suspected of illegal activity. The Coastal State has sovereign rights over the Seabed, Subsoil, Water column and Air space.

2. Contiguous Zone

Up to 12 nautical miles beyond territorial sea. The coastal state has jurisdiction to prevent violations of its Customs, Immigration or sanitary laws.

3. Exclusive Economic Zone (EEZ)

Up to 200 nautical miles beyond the territorial sea. All States enjoy freedom of navigation while the coastal state enjoys control over exploration and exploitation of living and non-living resources of the water column and the continental shelf.

4. Continental Shelf

Not to exceed 350 nautical miles from the baseline or not to exceed 100 nautical miles from 2500 meters Iso bath. The coastal state enjoys control over exploration and exploitation of living and non-living resources of the continental shelf and the subsoil. Beyond 200 nautical miles the state has to make a submission to the commission for exploration and exploitation of natural resources.

5. High Seas

Water column beyond national jurisdiction.

6. The Area

Seabed and the subsoil beyond national jurisdiction. Exploration and exploitation of the non-living resources at the seabed and subsoil are under International Seabed Authority.

It is important to note that the United States of America has not signed the UNCLOS convention. China on the other hand signed the convention in 1996 after more than a decade of negotiation but threatens to withdraw every now and then. (Wang, 2016)

International Seabed Authority (ISA): ISA was established in 1994 under the United Nations Convention on the Law of the sea. All deep-sea mining exploration and exploitation related activities are conducted through ISA. ISA is responsible for protection of Marine Environment, it monitors and controls all deep-sea activities in the Area. (ISA, 1994)

Various tools and techniques used for sea bed exploration and exploitation.

The deepest free dive ever made by a human was on 18/19 September 2014 by Ahmed Gabr in Dahab in the Red Sea to a depth of 332.35 meters as reported by the Dive Magazine. Although the dive was impressive, it is a long way from the deep-sea mining depths. With the development of deep-sea diving capsules or manned underwater vehicles, we can now go down to the deepest points in the ocean, such dives are mostly recreational or done for record breaking only they are very expensive for them to be used for deep sea exploration. (Dive Magazine, 2014)

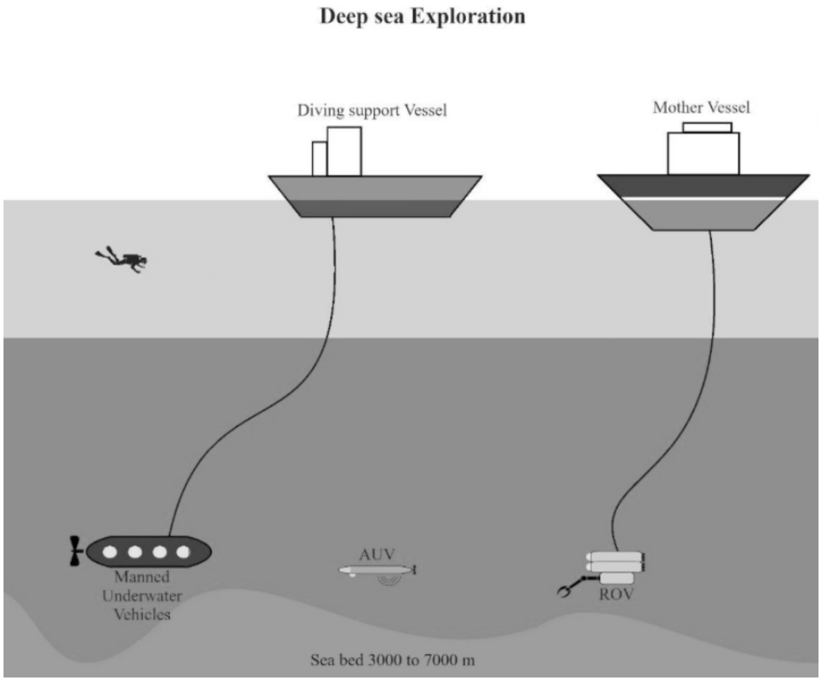

Figure 2: Deep Sea Exploration

Manned underwater Vehicles become very complex and expensive since they require life support systems, also they pose a serious risk to operators as well. The most economical and effective deep-sea exploration vehicles are "Remote Operated Vehicles (ROVs)", "Autonomous Underwater Vehicles (AUVs)" and Hybrid underwater robotic Vehicle (HURVs). (Wu, 2017)

- **Remote Operated Vehicles (ROVs):** These Vehicles are Remotely operated by an operator, as radio communication under the water can work only for short distance These Vehicles are always connected to the mother ship using a wire/cable also referred as an umbilical cord. If the cable breaks the ROV will be lost to the sea. Further all ROVs are divided into four different classes based on their application and size.

a. Observation class: They include Vehicles upto100 kgs weight with max power consumption around 15 KW and approximate diving depth of 300 mtrs only. They are mostly used for exploration and survey purposes only.

b. Light Work Class: ROVs between 100 to 1000 kgs with power consumption up to 55KW. They are deployed up to the depth of 1000 mtrs.

c. Work Class: Used for various work to be done at the seabed such as laying down underwater pipelines, cables, construction etc. Maximum operational depth is limited to 3000 mtrs.

d. Heavy work class: Highly specialized vehicles used up to the depth of 5000 mtrs with approx. power requirement of 110 KW.

An obvious flaw with ROVs is that they require constant human supervision and are prone to human error, also large communication cables present their own challenges. Often there is a significant time delay in communication which results in slow and sluggish operation.

Autonomous Underwater Vehicles (AUVs): These are automated vehicles that can be launched from a mother ship but do not require an umbilical cord as they can navigate by themselves using autonomous control systems. They are launched with specific goals and time frames. Once they have completed said goals, they autonomously rendezvous with the mother ship. They are also used for surveillance and military applications.

Even though AUVs are excellent underwater tools for Deep Sea mining but their application is limited to exploration roles only this is due to the limited battery capacity (power storage) that they have. With development in power storage techniques, we might see AUVs carrying out more heavy-duty roles as well. (Xiang et al., 2015)

- **Hybrid underwater robotic Vehicle (HURVs):** They are a combination of ROVs as well as AUVs Such Vehicles can change operational modes at sea combining advantages of both ROVs and AUVs. They are also the most commonly used tools for deep sea mining operations. The most important feature of such vessels is that they can be recharged under water just by reattaching the Umbilical cord. (Xiang et al., 2015)

Deep sea mining Techniques.

Deep sea mining operations are normally carried out in three steps as follows.

- **Prospecting:** This is the planning stage where various large mining corporations in collaboration with coastal states and in approval with international seabed authorities start researching and estimating various seabed reserves. Budget estimates are drawn up and scope of the mining operation is decided at this stage, based on present and future demand estimates of various products.

- **Exploration:** At this stage resource assessment and pilot mining work is started. Various AUVs, ROVs and deep towed photography instruments are used in combination of techniques such as echo-sounding, Sonar Scanning, Gravity exploration, Seismic exploration, Magnetic exploration, Electrical exploration to map the ocean floor and estimate the quantity of deposits. (Guo et al., 2023)

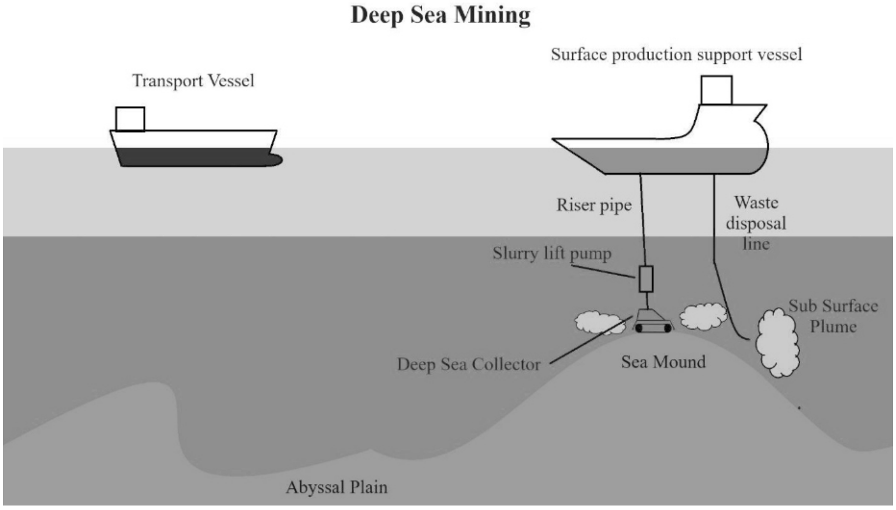

Figure 3: Deep sea Mining Operations

- Extraction: Extraction of nodules is easier compared to extraction of cobalt crust. Nodules can be simply picked up from the seafloor as they are not firmly attached to anything, but the cobalt crust is rigidly attached to the rock surfaces and the same needs to be excavated before it can be picked up. Various sea floor collectors are used to collect nodules/excavated sea crust. All collected solids are then pumped using a slurry lift pump through the riser pipe to a surface production support vessel. At the surface nodules/excavated crust is separated from the sea water, waste water and mud mixture are then drained back to the sea. Nodules or excavated crust is then delivered to a transport vessel for further processing.

Geo Politics of Rare Earth Elements

As evident from Table 1 Rare Earth Elements as well as Deep Sea mining are both very useful for various High-tech Military Hardware as well as Renewable Energy generation and storage equipment. Nations like China realized this long back and shaped their policies accordingly. Today China controls nearly 68% of global Rare Earth Element production.

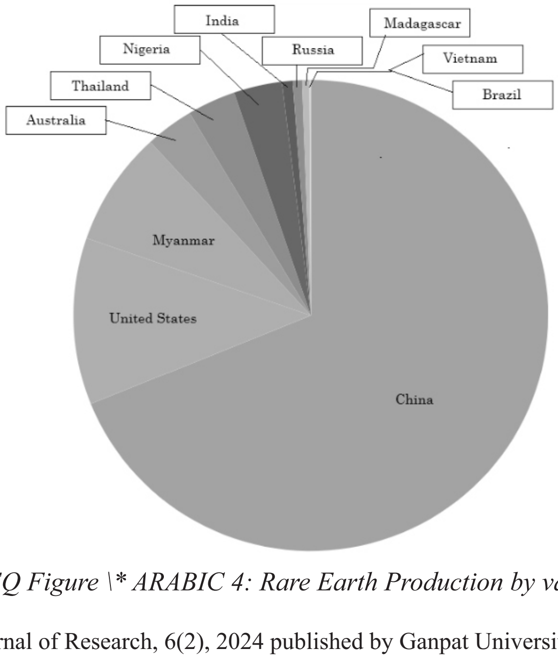

*Figure SEQ Figure * ARABIC 4: Rare Earth Production by various countries*

As evident from Figure 4, China controls a major chunk of Rare Earth Element production. China doesn't just control Rare Earth Reserves within its territory but also it has also secured mining rights in various African countries. China uses its control over Rare Earth to strong arm various nations around the globe.(Statista, 2024)

In 2010 China banned export of Rare Earth Elements to Japan following a territorial dispute in the south China sea. China's response was not just limited to the export ban, but President Xi also managed to publicly humiliate then Japanese prime minister Shinzo Abe. The ban brought Japan to its knees and the Abe administration was left with no choice but to agree to Chinese demands. Amid present day tariff war against US president Donald Trump China has again started using supply of rare earth as a bargaining chip. (Mulgan, 2014) (Waldersee & Steitz, 2025)

Geopolitics of Deep-Sea mining

Similar to Rare Earth mining on land China is trying to control Deep Sea Mining as well. China has used its Checkbook diplomacy by projects such as Belt and Road Initiative (BRI) to gain influence on a large number of nations across the globe. Small Nations are given loans for projects that do not make economic sense and the host country often defaults that particular loan putting it firmly under Chinese influence. (Singh, 2023)

With large number of small nations under Chinese influence and debt China has built up a strong vote bank in United Nations. With the help of its large vote bank, China is controlling various decisions made by the International Seabed Authority (ISA) in its favor. (Kardon & Camacho, 2023)

So far China has managed to secure more than 30 licenses across five Ares for deep sea mining exploration and with this continued trend it is likely to dominate Deep Sea Mining as well as the Rare Earth supplies across the Globe. (Lily kuo, 2019)

Conclusion

- Vast amount of Rare Earth Elements and other metals are available at the sea bed, we need to develop economical and environment friendly techniques for extraction by extensive research and development in this field.
- India needs to start making serious gains in the field of deep-sea mining as well as Rare Earth Production for securing safe and stable supply of Rare Earth Elements.
- Additional research and training are required in the Maritime and oceanographic field of studies.
- ROVs, AUVs and HURVs are going to be in large demand for the next decade or more. Although the Govt. of India has taken considerable steps under Atmanirbhar Bharat, more budget allocation and initiation is required in this sector.
- The Govt. of India needs to promote training and innovation in the field of deep-sea diving.
- Further work is required on deep sea exploration techniques.

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