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Techno Economic Analysis of Rooftop Solar System Along with Potential and Future Prospects in India

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Abstract— ***The mitigation of global energy demands and climate change are the most important factors in the modern days. Moreover sustainable energy security is the another key issue which stimulate to think the researchers, manufacturers and government to develop the solar energy extensively. Development and application of solar energy have been regarded by the government of India and common people, and they thought that solar photovoltaic energy can provide more energy in future compare to other renewable energies. In the last decade, solar photovoltaic energy research and development has supported by the central government and state governments. This paper discusses the solar energy potential, development and future prospects in India. Some key policies and initiatives undertaken by Indian government to promote solar energy in India are also highlighted. Techno economic analysis of a typical roof top solar system is also analysed with Indian context which will be helpful for decision makers and various stakeholders.***

Keywords— ***Jawaharlal Nehru National Solar Mission (JNNSM), Solar Energy Corporation of India (SECI), Renewable Purchase Obligation (RPO) , Renewable Energy Credits (REC), Roof top solar, Ministry of New and Renewable Energy (MNRE)***

I. INTRODUCTION

India has been a witness to chronic energy poverty and almost one fifth of its population is without access to electricity. This also explains why India's per capita electricity consumption is among the lowest in the world as shown in Fig. 1[1]. Furthermore, the availability of electricity in many areas is limited to a few hours during the day. Thus, at present, a significant amount of demand is unmet owing to limited availability and accessibility of electricity.

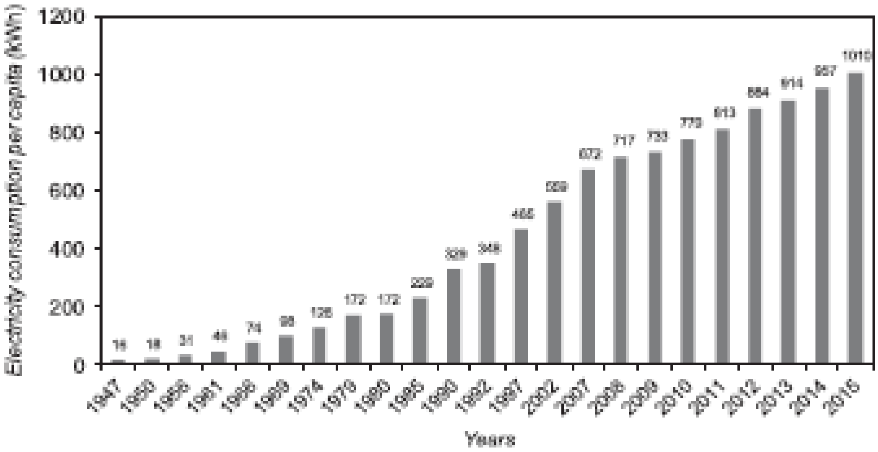

Fig 1: Per capita consumption of electricity in India

As per the Maximum Energy Security Pathway scenario predicted by "IESS – 20471 Tool" developed by Niti Aayog, Government of India (GOI), India's electricity demand, which was 876 Terra Watt-hour (TWh) in 2012 could rise up to 5518 TWh by 2047 in the case of 'Determined Effort' or default case scenario – the level of effort which is deemed most achievable by the implementation of current policies and programs of the government. If heroic efforts were made to reduce energy demand, the same could be brought down to 3730 TWh by 2047[2].The solar energy development, challenges, policies, frameworks, Government of India (GOI) initiatives, future perspectives etc have been outlined in the literatures[3-8].

II. SOLAR ENERGY POTENTIAL IN INDIA

India lies in the sunny belt of the world. The scope for generating power and thermal applications using solar energy is huge. Most parts of India get 300 days of sunshine a year, which makes the country a very promising place for solar energy utilization [1]. The daily average solar energy incident over India varies from 4 to7kWh/m2 with the sunshine hours ranging between2300 and 3200 per year, depending upon location [1]. India has an estimated potential of about 749GW [1,5] of solar energy to be harnessed for reducing energy poverty in the country . In terms of solar energy potential Rajasthan leads the table with 142GW (Fig. 2) followed by Jammu and Kashmir (111GW).

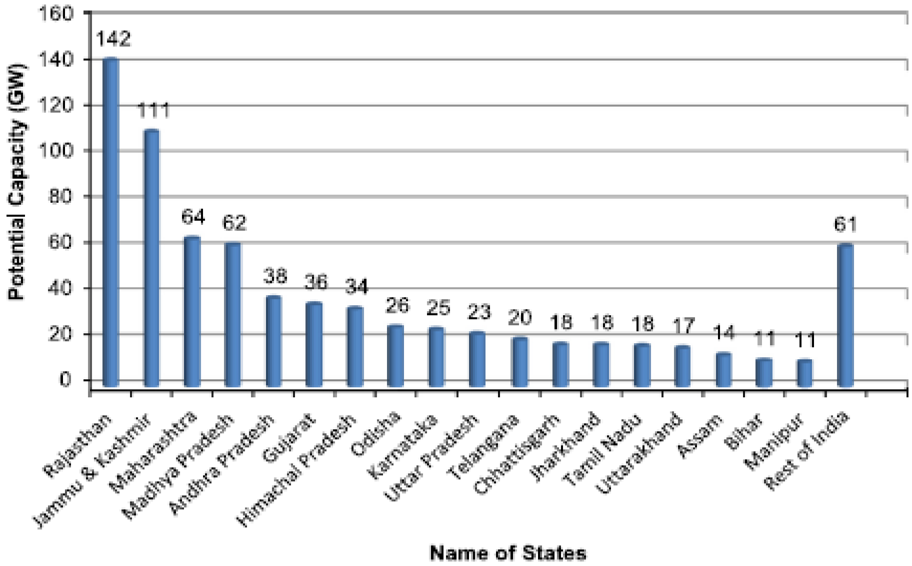

Fig 2: State wise solar energy potential in India

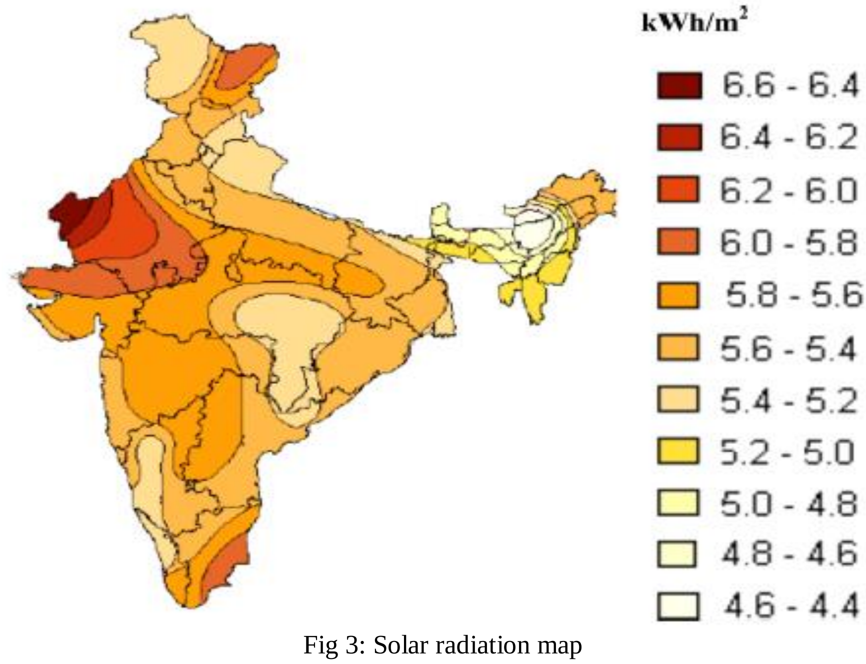

Fig 3: Solar radiation map

India receives enough solar energy to generate more than 500,000 TWh per year of electricity, assuming10%conversion efficiency for PV modules .It is three orders of magnitude greater than the likely electricity demand in India by the year 2015 [5]. Fig. 3 shows map of India with solar radiation levels indifferent parts of the country[1]. It can be observed that although the highest annual global radiation is received in Rajasthan, northern Gujarat and parts of the Ladakh region, the parts of Andhra Pradesh, Maharashtra, and Madhya Pradesh also receive a fairly large amount of radiation as compared to many parts of the world especially Japan, Europe and the US where the development and deployment of solar technologies is maximum .

III. SOLAR ENERGY TARGET AND FUTURE PROSPECTS

Recently Government of India has revised the target of Jawaharlal Nehru National Solar Mission *(*JNNSM) from 20,000 MW to 100,000 MW of solar power capacity by 2022 [1,2]. To achieve the ambitious target, the Indian government has set state wise targets(Fig. 4) to be achieved by2022 [1]. The Northern region has a target of about 31 GW followed by Western region (28.4 GW), Southern region (26.5 GW), and Eastern region (12.2 GW).

Fig 4: State wise break up of solar energy target by 2022

The revised target includes 40,000 MW of Solar Roof top projects and 60,000MWoflarge and medium scale solar projects. Up to2014 2015,3743 MW of grid connected solar power already commissioned and year-wise targets from2015–2016 to 2021– 2022 are presented in Fig. 5.

In 2014, Indian government rolled out a scheme for development of Solar Parks and Ultra Mega Solar Power Projects which envisages supporting the States in setting up solar parks at various locations in the country with an objective to create the required infrastructure for setting up of Solar Power Projects. The solar parks will have suitable developed land with all clearances, transmission system, water access, road connectivity, communication network, etc. This scheme facilitates faster installation of grid-connected solar power projects for electricity generation on a large scale. The Indian government plans to set up at least 25 Solar Parks and Ultra Mega Solar Power Projects to cover the 20,000 MW of solar power capacity within a span of 5 years, starting from 2014 to 2015.

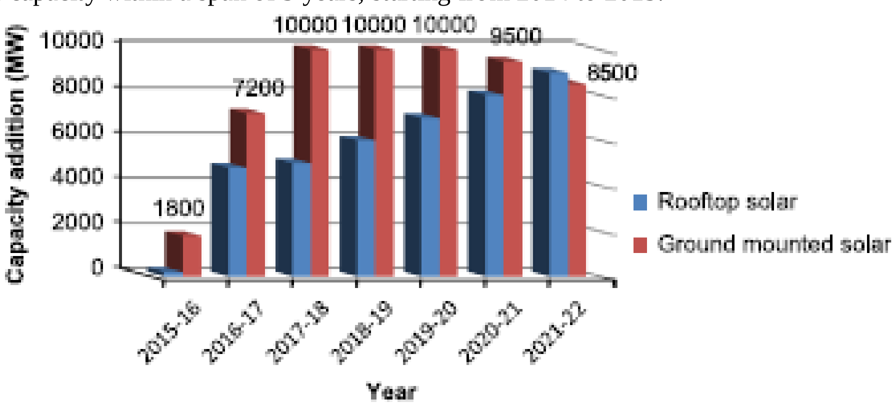

Fig 5: Revised year wise target under JNNSM

IV. TECHNO ECONOMIC ANALYSIS OF ROOF TOP SOLAR SYSTEM

Rooftop solar [9,10] power production has massive potential to transform the solar power production and distribution in the country. Installation of PV modules on rooftop of the buildings generates electricity for self-consumption and power distribution. By proper designing and matching of the electrical loads, it is possible to become self-sufficient in meeting electricity demand of the building by Installation of Solar PV rooftop systems. SECI has been entrusted by MNRE for implementation of a large scale grid connected rooftop pilot projects, with 30% subsidy support from National Clean Energy Fund (NCEF).The system cost also includes annual maintenance charges for 2 years.

The manner of disbursal of subsidy is as follows:

- 20% after successful installation and commissioning of the system .
- 5% after one year of successful operation of the project.
- Balance 5% after two years of successful operation of the project.

A. Techno economic analysis of roof top solar PV system:

1. Calculation of number of solar panels required

We begin by estimating the total energy are used. We need to know the rating and quantity of each type of load, how many hours they from the load side. The energy per day can be calculated as shown in equation (1)

$$E_{day} = \sum_{i=1}^{n} \frac{(U_i P_i n_i)}{1000} \text{ KWH} \qquad (1)$$

Where i is the index of each type of load such as fan, lights, TV etc, U_i=number of hours device type i is used per day, P_i=power rating of i_{th} device type, n_i=number of devices of i_{th} type. Thus, the total PV generation capacity required can be calculated as

$$P_{pv} = \frac{E_{day}}{(S_d * d)} \text{ KW} \qquad (2)$$

where, S_d= average number of hours the sun shines at the site, d = de-rating factor, which takes in to account the effects of efficiency and changes in the solar generation during the day. The typical values of S_d, and d are 7 hours (in west Bengal) and 80% respectively. From this the number of solar panels required can be calculated by this equation no. (3)

$$N_p = P_{pv}/P_o \qquad (3)$$

where, P_o is power output capacity of each panel.

2. Calculation of number of batteries required

The number of batteries N_{bat} can be obtained as follows

$$N_{bat} = (E_{day} * n_d)/(V_{bat} * I_h * DOD) \qquad (4)$$

where, n_d is the number of days of backup power required, V_{bat} is the voltage rating, I_h is the ampere-hour rating and DOD is the depth of discharge of the battery system. Thus, equations (1)-(4) represent the mathematical model for choosing the number of PV panels and batteries from the technical requirement of the load.

3. Calculation of size of inverter

The capacity of inverter is determined by the expected peak demand of the load. The peak demand of the load is estimated by using the relation between the connected load and the diversity factor (DF) of the load where diversity factor is ratio of maximum demand to total load connected.

$$P_{inv} = \frac{\sum_{i=1}^{N} P_i n_i}{DF} \qquad (5)$$

4. Profit from Rooftop Solar System

The objective of this part of the study is to determine the total economic profit derived by shifting from grid power to rooftop solar power. Let C_{grid} be the cost of power from grid, C_{pv} be the cost of rooftop solar system considering the subsidy. Assuming a lifetime of L years, and cost of unit of energy charged by the utility as C_u, the cost of power from the grid can be calculated as

$$C_{grid} = 365 * E_{day} * C_u * L \qquad (6)$$

The roof top solar system consists of four major components, namely, PV panels, battery storage system, inverter, and charge controller. Thus the total cost of the roof top solar system without considering any subsidy ($\overline{C_{pv}}$) can be calculated as

$$\overline{C_{pv}} = (C_{panel} + C_{bat} + C_{inv} + C_{ctrl}) \qquad (7)$$

Considering a percentage subsidy by government as $P_{subsidy}$ the total cost of the roof top solar system C_{pv} is

$$C_{pv} = (1 - P_{subsidy}) * (\overline{C_{pv}}) \qquad (8)$$

Where $C_{bat} = N_{bat} * cost\ per\ battery$ and

$$C_{panel} = N_p * cost\ per\ PV\ panel.$$

Thus the overall profit achieved by shifting from grid to rooftop solar is

$$Profit = C_{grid} - C_{pv} \qquad (9)$$

The benefit of shifting to roof top solar includes independence from the grid, and thus the user can avoid power cuts. It can also be noted that this is right time for the consumers to shift to rooftop solar, to take advantage of the subsidies available.

5. Calculation of Pay Back Period

We need to find the time required to make the savings equal to the amount invested. Mathematically this can be expressed as

$$E_{day} * C_u * 365 * Y_{pay-back} = C_{pv} \qquad (10)$$

where, $Y_{pay-back}$ is the payback period in years. By rearranging the above equation, we can calculate the payback period as follows

$$Y_{pay-back} = \frac{C_{pv}}{E_{day} * C_u * 365} \qquad (11)$$

According to the C_{O2} base line database prepared by Central Electricity Authority (CEA) under the ministry of power, Government of India, the weighted average emission factor for thermal power plants is 0.82 Tonnes of C_{O2} per MWh of energy generated. Using this factor we can determine the reduction of C_{O2} emission on account of shifting to rooftop solar for a lifetime of 25 years as shown in equation (12).

$$CO2_{emission} = E_{day} * 0.82 * 365 * \frac{25}{1000} \quad \text{ton/MWh} \qquad (12)$$

B. Cost benefit analysis:

Considering typical residential load with energy consumption per day 9.57 kwh [10] the details cost benefit analysis with technical parameters are given in table -1.

Table-1: Design and Cost Benefit Analysis of a Typical Roof Top Solar System

Total energy consumed per day in KWh	9.57
Power rating of the solar panels (P_{pv}) in Kw	9.57/(7*0.8)=1.7
Number of solar panels (N_{pv}) required with power rating of 250 Watt each	1.7*1000/250≈7
Cost / solar panel of 250 watt in Rs.	13100
Total cost of solar panels (A) in Rs.	7*13100=91700
Number of Batteries (12 V, 220 A-h each) required to have backup for 3days(N_{bat})	9.57*3*1000/(12*220*0.5)≈22
Total cost of batteries in Rs.(B)	22*12000=264000
Cost of charge controller in Rs.(C)	4500
Inverter size i.e. installed capacity/diversity factor in Watts	1025/1.7=603
Cost of inverter in Rs. (D)	603*7.4=4462
Total cost of whole equipment i.e. (A + B + C + D) in Rs.	364662
Consider the subsidy in %	30%
Total cost of whole equipment after subsidy in Rs.	3,64,662 - 1,09399 = 2,55263
Total electricity bill for 25 years without using solar power considering Rs. 6 / unit	523957
Total profit using solar power in Rs. In 25 years	523957-255263=268694
Total CO2 emission reduction in 25 years	9.57*0.82*365*25/1000 = 71.6 Tons
Payback period in years	(2,55,263 / 5,23,957) * 25 = 12.17≈**12.2**

V. SOLAR ENERGY POLICIES

Several policy [1] instruments associated with solar energy are described below:

1. Renewable Purchase Obligation (RPO):

This market instrument mandates State and private distributors as well as captive power producers to purchase solar generated electricity. National Action Plan on Climate Change (NAPCC) mandated 5% of States electricity purchase from renewables in 2010, with 1% increase per year until 2020 (15% cumulative). The JNNSM also proposes RPO [1] with 0.25% solar electricity of total purchase by 2013 and 3% by 2022. It is a minimum level determined by the federal Government, and each State can have their own arrangement.

2. Renewable Energy Credits (REC):

This scheme (with a specific quota for solar) was proposed in NAPCC [11] by the MNRE and the Regulatory Commissions. Accordingly, 1 MWh of renewable generated electricity is treated as a bundled good. In one part, it is sold as electricity and the other part as REC which can be traded between States. While the price for REC is determined in the free market, it still needs to be controlled by upper-bound and lower-bound prices. The lower-bound and upper-bound are currently US$0.24/kWh and US$ 0.32/kWh determined by Central Electricity Regulatory Commission (CERC). RECs are traded in two main exchanges, Indian Energy Exchange Limited in New Delhi and Power Exchange India Limited in Mumbai.

3. Feed-in Tariff (FIT):

The responsibility to fix tariffs for purchase of renewable power lies with CERC and SERC. CERC sets the guidelines and norms for setting tariffs; however, States can remain flexible and announce their own version of tariffs. The minimum tariff determined by CERC is currently US$ 0.36 kWh for solar photovoltaic. Government awards FIT [1] contracts in a competitive process and with different mechanisms including first come first-served (FCFS), 'beauty contest' (Selecting projects based on predefined criteria) and reverse auction. When any FIT contract is awarded to a project, it will remain fixed for a period of 25 years.

4. Long-term power purchase contracts:

In this mechanism, the MNRE provides incentives for distribution utilities to make a long-term power purchase contract with solar power developers. This incentive is intended to cover the high cost of initial investment.

5. Payment Security Mechanism:

The MNRE has announced a policy to provide backup financial support to NTPC Vidyut Vipanan Nigam Limited (NVVN) to meet their requirement of funds, in case of any fault in payment by the distribution utilities. A certain amount of money is reserved as payment security. It improves the likelihood that grid solar power projects will become bankable for investors.

6. 100% foreign Investment:

With an aim to attract the required financial resources for increasing solar generation capacities, 100% foreign investment is permitted in equity.

7. Tax holidays:

The developers can benefit from 10 years exemption from corporate tax during the first 15 years of the project's life.

8. Viability Gap Funding (VGF):

VGF is a capital subsidy which provides a grant funding to reduce the upfront capital costs of installed capacities. MNRE proposes VGF in a reverse bidding process to developers.

VI. CRITICAL ISSUES

There are several issues are presents in India for solar power development. The issues associated with solar power development are given below:

- The deficiency in the relationship between the government and industry.
- The need for distinct, goals driven and collaborative R&D projects to help India to accomplish technology governance in photovoltaic.
- Training and evolution of human amenities to operate industry expansion and photovoltaic acquisition.
- The requirement for intra industry cooperation in growing the PV supply chain, by using the technical enlightenment, sharing through the workshops and conferences, in alliances with ‘balance of systems’ manufacturers and in assembling and publishing accurate trends, market data and projections.
- The need to construct consumer consciousness about the solar technology, its usage and economics.
- Complexity in the structure of subsidy and implication of too many organizations or agencies like Ministry of New and Renewable Energy (MNRE), Solar Energy Corporation of India(SECI), Indian Renewable Energy Development Authority (IREDA), electricity regulatory commission and electricity board makes the expansion of solar photovoltaic projects very difficult.
- Land allocation and Power Purchase Agreement (PPA) signing is a long process under the GBI (Generation Based Incentive) scheme.
- Manufacturers are mainly buying their all equipment for solar power generation, from the foreign market due to the low prices compared with the local Indian market .So, local market facing losses due to the import of solar power generation equipment from foreign.
- All above discussed issues and challenges are very crucial in solar power development scenario of India. Government of India has focused on that all issues and trying to remove the barriers by taking various schemes, policies and missions related to solar power like ‘Jawaharlal Nehru National Solar Mission’

VII. GOVERNMENT INITIATIVES AND STIMULI TO SOLAR ENERGY

Several government initiatives and driving forces for solar energy development are given below:

- In the first step, the Central Government hosted the biggest event for renewable investors at the **Re-Invest Summit** in New Delhi in February 2015. The Re-Invest Summit can be seen as a turning point for solar since it linked manufacturers, developers and investors, and also brought together different Ministries (stakeholders) engaged in the development of renewables. This type of national campaign is shaping a supporting social and political environment for the solar sector, bringing consensus between stakeholders and attracting local and international investors to the sector in the future.
- The US President's visit to India in 2015 with a joint commitment for emissions reduction can be seen as another landmark for solar electricity. It shapes a more favourable political support for the future of renewables and solar in particular.
- The Indian government's pledge in the 2015 **Conference of Parties (COP21)** in Paris and then its ratification in 2016 can form a clear international commitment and also a political determination for a low carbon future in India.
- The government has requested the Ministry of Power to increase the RPO for solar to 10.5% in order to ensure attaining the 100 GW goal by 2022.
- To achieve the objective of JNNSM **Ministry has sanctioned various Center of Excellence in Solar Energy like** National Centre for Photovoltaic Research and Education (NCPRE) at IIT Bombay, Indian Institute of Engineering Science and Technology (IIEST) in Kolkata (research on "T**hin silicon solar cells and photovoltaic systems**"), "**Solar Thermal Research and Education**" at IIT Jodhpur, ***National Institute of Solar Energy at Gurgaon*** etc.
- ***Achievement linked incentive*** has been declared by MNRE vide letter no-03/8812015-16/GCRT under "grid connectd roof top and small solar power plant programme" which is given in table-2

Table-2: Achievement Linked Incentives for Solar Energy

Achievement vis-à-vis target allocation	***Incentive for general category states***	***Incentives for special category states***
80% and above within sanctioned period	*Rs-18750/Kw*	*Rs-45000/Kw*
Between 50%-80% within sanctioned period	*Rs-11250/Kw*	*Rs-27000/Kw*
Below 50%/ delayed commissioning upto 6 months beyond sanctioned period	*Rs-7500/Kw*	*Rs-18000/Kw*

VIII. CONCLUSIONS

Government of India has given more emphasis on promotion of solar power in Indian power scenario. Currently India is in the top ten ranked countries in the world for investment, capacities addition and creation of job opportunities in solar power. Solar power can also provide a better economical scenario after successful implementation of solar mission for all states of India, especially for some undeveloped states, where the potential of solar power generation is very good but not utilized till date. From the above discussion, it is concluding that the solar power takes an important role in the future power development in India due to the major initiatives and dedication of Government of India. The tariff for solar power has fallen from Rs 18 per unit a few years ago to an unprecedented level of below Rs 5 per unit – a big accomplishment to promote clean energy.

Government of India should give more emphasis to make success on their mission: "24X7 Power for all" by 2020.In spite of having several challenges the government should come forward with better conducive policy to reach the solar target in reality. Through this a cleaner and greener India with sustainable energy security can be achieved.

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