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Assessment of energy consumption pattern and roof top solar power potential in western Himalayan city

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ABSTRACT

The present investigation on energy consumption pattern and roof top solar power potential was conducted in Solan city of Himachal Pradesh, India. Four sectors namely residential, institutional, industrial and commercial were selected. It was found that the maximum monthly overall electricity consumption was 352.22 kWh. The overall number of LPG cylinders used in domestic sector during summer was 1.34 and in winter it was 3.69. The average electricity consumption during summer and winter seasons in case of hospital was 647.50 and 662.30 MWh, respectively, in case of bank it was 136.29 and 182.62 MWh, respectively, for private and government schools it was 525 MWh and 385 MWh, respectively. The overall LPG consumption in intuitional sector was 3.25 and

7.75 cylinders for summer and winter, respectively. The monthly electricity consumption in small and micro industries for summer was 2,419 MWh and 2,156 kWh, respectively and for winters it was 2,610 MWh and 5,120 kWh, respectively. The annual energy consumption and carbon dioxide emission of Solan city was hence calculated to be 287.17GWh and 0.55 million tonnes, respectively. The annual rooftop solar power potential of Solan city was worked out to be312.08GWh. It showed that solar power if used judiciously in Solan city, it would be sufficient to fulfill the energy needs of the city and also to curb carbon dioxide emission in the city due to usage of non renewable energy resources.

Keywords: Energy consumption, domestic, commercial, solar power

1. INTRODUCTION

Energy is considered as one of the prime and a significant factor in economic development. Limited fossil fuels and environmental problems associated with the conventional sources of energy have necessitated the need for sustainable renewable energy, which can mitigate climate change (EkiNs-Daukes, 2009). The amount of solar radiation reaching the surface depends on location, atmospheric effects (cloud cover and water vapour) and topography (Fu and Rich 1999). Topographic effects such as elevation, slope, and orientation affect the amount of radiation reaching a ground (Kang *et al*., 2002).

In India, the total energy consumption of domestic sector has been around 40 to 50% (TEDDY, 2003). The per capita energy consumption in India was 800 kgce (Kilogram coal equivalent) annually in 2013 compared to global consumption of 1,818 kgce annually (Garg, 2012). The sector-wise energy consumption pattern in India from 2005 to 2006 was 6.9% in agriculture, 44.45% in industries, 16.8% in transport and 8.06% in others sectors, while in 2010 to 2011 it was 7.32% in agriculture, 43.63% in industries, 17.5% in transport, 13.73% in residential and commercial sectors and 8.27% in others sectors (TERI, 2013). According to Brohmann*et al.* (2009) household energy consumption contributes to almost 30% to the total final energy consumption, which is second most rapidly growing area of energy use after transport.

Due to increasing greenhouse gas emissions, lack of environmental safety measures in energy production techniques, escalating energy prices and depleting conventional energy resources (Nguyen and Pearce 2010; Choi *et al*., 2011), countries are diversifying energy sources and including renewable generation in their policy decision**.** Energy prices are positively correlated with sustainable energy use (Brohmann *et al.*, 2009). Continuing dependence on traditional energy sources, high government subsidies for LPG and kerosene, poor distribution of subsidies, have benefited the high income households (IEA, 2007). According to Government of India 668 million people don't have access to present sources of energy and it aims to bring down to 395 million people by 2030 (WHO, 2014).

Sharma (1981) reported that the per capita domestic energy consumption in rural areas of India was 0.35tce (tonne of coal equivalent) annually. Sinha *et al*. (1998) has studied energy consumption in the rural areas of India and found that fuel wood consumption was 58% followed by dung cake (21%), agricultural residues (21%) and kerosene consumption 11%. The Integrated Energy Policy Report of the Expert Committee (Planning Commission, India in 2006) recommended that every household should be given 30 units of electricity on monthly basis for lighting, space heating/cooling, and 6 kg of LPG for cooking. Aggarwal (2009) carried out a pilot survey to identify the energy consumption pattern in Himachal Pradesh indicated that fuel wood consumption was 95.2%, kerosene (38.45%), LPG (70%) and crop residues (94.5%). Aggarwal and Chandel (2010) concluded that fuel wood consumption constituted about 52% of the total energy consumption of the Himachal Pradesh. The National Sample Survey 2004-05 revealed that in Himachal Pradesh monthly fuel wood, kerosene, LPG and electricity consumption was about 195 kg, 4.6 litres, 8.4 kg and 82.61 kWh, respectively. Ingole *et al*. (2013) studied annual domestic energy consumption from various energy sources in Duryapur block of Maharashtra; revealed that firewood contributed 48%, dung cake 7%, kerosene 14%, LPG 4% and electricity 27%. Dash (2013) suggested that high income households consume highest energy as they use modern (high cost) appliances, having more number of vehicles thereby consuming more oil. Chhoerup *et al.* (2014) studied cooking energy consumption pattern in snow bound area of Lahaul and Spiti district of Himachal Pradesh covering 300 households showed that energy consumption was coming from fuel wood (55.46%), electricity (0.07%), dung cake (26.50%), kerosene (9.33%) and LPG (8.64%). Use of fuel wood in urban sector was found to be nil (Sarmah and Bhattacharyya, 2015). Gautam et al. (2015) revealed that the use solar power could help in mitigating the blackout problem in Nepal as it receives well solar in solation. Presently, about 60% of India's power requirements are met by burning coal, which is damaging the environment so, India needs to reduce its dependence on fossil fuels for a better future (Gulati *et al.*, 2016).

In order to meet out the energy demand by using solar power, investigations were carried out. Wiginton *et al*., (2004) in Ontarioa has developed five-step procedure for estimating total rooftop Photovoltaic (PV) potential. According to Izquierdo *et al*., (2010) photovoltaic systems would provide 4% of total electricity demand. Bergamasco et al. (2011) have shown that, the solar energy potential over the region worked out to be 6.9 TWh/year. Carl (2014) estimated that solar power rooftop potential was 190 million kWh annually which was 17% of the total electricity available to island in 2012. He found that if PV pants installed at 4,460 buildings it could provide power to 31,000 houses annually. Ramirez *et al*. (2015) proposed procedure to assess solar potentials at the municipal scale and to design roof top PV exploitation plans, which were more appropriate to fulfill the local energy requirements. Mandal and Panja (2015) found that the average energy generation from the system was around 3 - 4 kWh/day in the rainy seasons. These results were the evidence of reliability and feasibility of the present system and it will help to reduce the electricity bill for the consumers who have maximum consumption during daytime. The total realistic market potential for rooftop solar PV in urban settlements of India is found to be around 124 GW (Tripathi *et al*., 2015). *Ntsoane (2017) found that out of total* rooftop area of 824 071 m^2 within the central business district of the City of Johannesburg 46% of rooftop space was available for rooftop PV system.

India has vast solar energy potential. Solar photovoltaic rooftop has emerged as a potential green technology to address climate change. About 5,000 trillion kWh per year energy is incident over India with most parts receiving 4-7 kWh/m^2/day. A small fraction of the total incident solar energy can meet the entire country's power requirements. With a strong commitment to increase the renewable sources based energy capacity to 175 GW by 2022, India has a target to install 100 GW of solar energy out of which 40 GW would be the share of grid connected solar PV rooftop (Goel, 2016). The Ministry of New and Renewable Energy, Government of India has fixed the target of solar rooftop power production as 1,000 MW during the period of 2018-19 out of which 147.12 MW has been achieved till 31st May 2018 (MNRE, 2018).

The high consumption of fossil fuels has resulted in increase of greenhouse gases (GHGs), which are mainly responsible for global warming. The carbon dioxide concentration in the atmosphere has touched 400 ppm mark compared to 274 (ppm) (pre-industrialization era). India's per capita carbon dioxide emissions were much lower than those of developed countries. The National Action Plan on Climate Change has targeted 15% of India's energy from renewable resources by 2020.

Himachal Pradesh being the mountainous state has all sorts of resources and the state's priority is to produce energy through solar power. About 250-300 sunshine hours are available in the state, which can be utilized for power generation. Solan is fast developing city in the state, which has a total population of 39,256 residing in 15 wards and planning area covers 33.43 kilometer square of land (Largest city area in Himachal Pradesh). It is located between the longitudes 76.42 and 77.20^0 East and latitude 30.05 and 31.15^0 North. Since it falls between Chandigarh and Shimla, has high vehicle movement and high energy consumption emitting more greenhouse gasses. Keeping in view of this, the present study aims to carry out survey on energy consumption pattern and assessment of roof top solar power potential in Solan city to meet out the energy need. In addition to domestic sector, commercial and institutional buildings were also studied.

2. MATERIAL AND METHODS

In order to assess the trends and distributional pattern of primary energy consumption, 5 wards out of 15 wards were selected randomly in Solan city of Himachal Pradesh (Figure 1). In the second stage, 25 households from each selected ward were selected randomly. Primary data was collected by using well designed and pretested schedule for the purpose. The description of selected and total respondents has been presented in Table1. The sectors selected for primary data collection were Commercial, Industrial, Institutional and Residential.

Table1 Description of selected and total respondents

Particulars	Selected number	Total number
Households	125	9,803
Population	553	39,256
Micro industries	2	426
Small industries	10	60
Hospital	1	5
School	2	9
Bank	1	9
Hotel	2	10

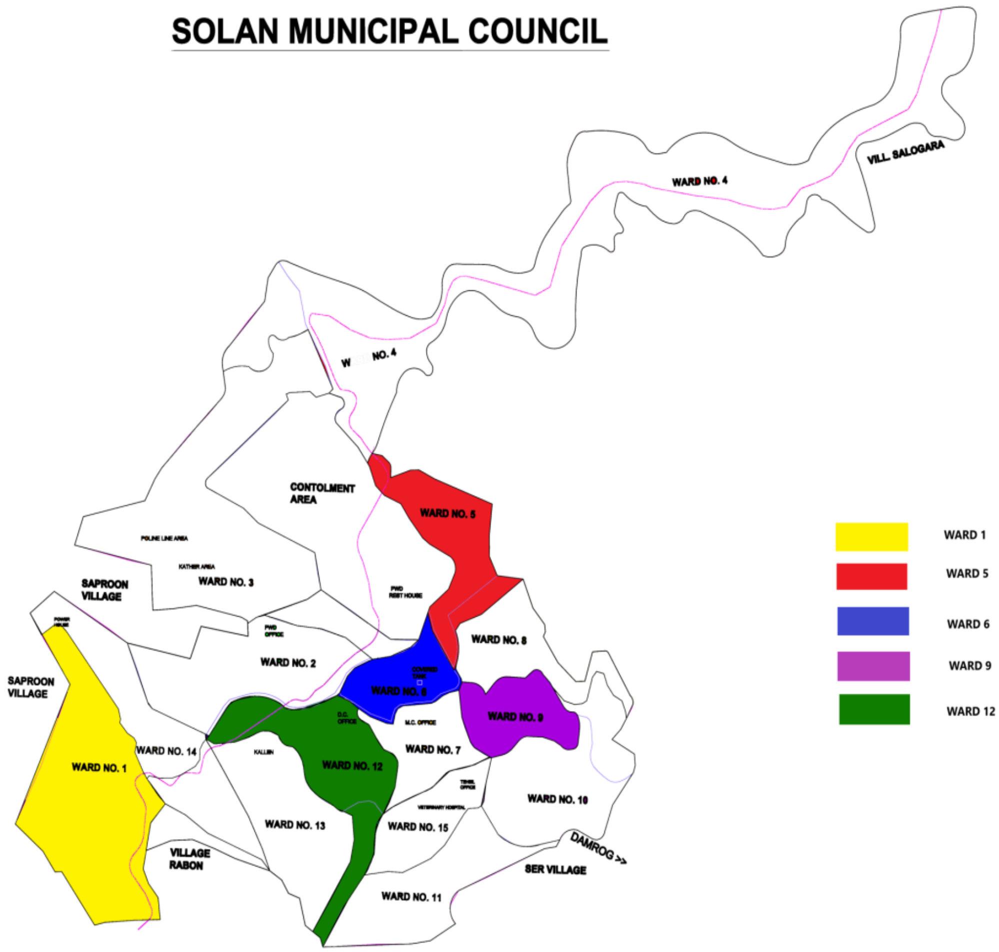

Figure1 Map of study area in Solan city

In order to assess the primary energy consumption in domestic sector, the households were categorized into income and family size. The households were divided into four income groups in US$ (Shorrocks *et al.,* 2016) as Low income: $1,200-$2,700; Medium income: $2,700-$6,700; High medium income: $6,700-$13,300 and Rich: >$13,300. Since no household was found having income of >$13,300 in the study area, hence did not discussed. The households were divided into four family size viz. Small :< 4 members; Medium: 4 - 5 members; Large: 6 – 7; Very large :> 7. The selected industries were categorized according as Micro Enterprises: >$33330; Small Enterprises: $33330-$66700 (Enterprises Development Act, 2006). Private schools and Government schools were selected randomly. One hospital, one bank and two hotels were also selected randomly.

Conversion factors used to translate various energy sources into coal equivalent are (Kumar, 2015):

1. Petroleum oil (litres): 0.20 kg coal equivalent per unit
2. LPG (kg): 1.19 kg coal equivalent per unit

The coal equivalent was converted into kWh using Electricity (kWh): 0.70 kg coal equivalent per unit

Carbon dioxide emission

The carbon dioxide emission from the burning of conventional fuels was estimated by the product of total fuel consumption and their emission factors (Kumar, 2015). Conversion factors used to translate various energy sources into carbon dioxide emissions are

1. Electricity (kWh): 0.87 kg carbon dioxide per unit
2. Petroleum oil (litres): 2.46 kg carbon dioxide per unit
3. LPG (kg): 2.78 kg carbon dioxide per unit

Assessment of roof top solar power potential in domestic and commercial buildings

Placing solar panels on unused rooftop space can subsidize the electricity demand that a building requires (Macdonald, 2014). The rooftop solar power potential in terms of installed capacity (kilowatt peak) was calculated with an assumption that the area required for installing one kilowatt peak of solar photovoltaic module is 10 square meter (Jadhav *et al.,* 2016). The south facing roof top area of domestic, commercial and institutional buildings was measured in selected buildings.

Analytical Tools

a. Analysis of variance was performed and data was analysed by one way classification to test the primary energy Consumption pattern of buildings and roof top solar power potential of buildings for 5 wards.

b. Overall energy consumption in different sectors in kWh has been calculated as :

$$\sum_{particulars} \frac{ener\ gysource * total\ population\ of\ diffrent\ sectors}{total\ number\ of\ respondents}$$

c. The 5 wards taken were 1, 5, 6, 9, 12, which were numbered as 1, 2, 3, 4, 5, respectively.

3. RESULTS AND DISCUSSION

The perusal of the Table 2 1indicated the category wise distribution of selected households in which 70 households came under the annual income group of $2,700-$6,700 and 55 households were found in the annual income group of $6,700-$13,300. According to family size it was found that 14 households came under family size <4, whereas, the maximum number of households (98) were categorized under 4-5 number of family size and the least number of 13 households were found under 6-7 family size.

Table 2 Category wise distribution of selected households (number)

Particular	Wards					
	W_1	W_2	W_3	W_4	W_5	Total households
Annual Income group						
$2,700-$6,700	12	25	13	10	10	70
$6,700-$13,300	13	0	12	15	15	55
Family size (Number)						
<4	14	0	0	0	0	14
4-5	11	25	22	23	17	98
6-7	0	0	3	2	8	13

Table 3 indicated that overall 324.33 kWh and 291.95 kWh units of electricity were consumed monthly during summer season by the households falling under the annual income group of $2,700-$6,700and $6,700-$13,300, respectively. The study showed that the income played a vital role in electricity consumption; this is in line with Dash (2013). Households when categorized with respect to family size the different classes showed an increasing trend of an overall of 331.07kWh being the lowest and 352.22 kWh being the highest.

Table 3 Monthly average electricity consumption (kWh) of selected households

Particular	Overall electricity consumption		Diesel & Petrol	Overall LPG cylinder consumption	
	Summers	Winters		Summers	Winters
Annual Income group					
$2,700-$6,700	324.44	384.42	59.20	1.43	1.96

$6,700-$13,300	291.95	384.71	48.98	1.34	2.27
Family size (Number)					
<4	331.07	357.14	58.57	1.07	1.43
4--5	347.95	379.95	59.44	1.45	1.92
6--7	352.22	505.56	52.57	2.33	3.69

The overall electricity consumption while observing the trend in annual income group for $2,700-$6,700and $6,700-$13,300 was 384.42 and 384.71 kWh, respectively. The energy consumption pattern during winter season under the categorization of family size the overall electricity consumption showed an increasing trend with respect to the increasing family size with an overall of 357.14 kWh consumed by the family size of < 4to 505.56 kWh consumed by family size of 6-7. This showed that larger the family size and income, more was the electricity consumption; the same results were reported by Rajan and Singh (2017).

The overall petroleum oil used in vehicles and generators was taken into consideration. The overall petroleum oil consumption of 59.20 litres and 48.98 litres were found in the annual income group of $2,700-$6,700 and $6,700-$13,300, respectively. In context of family size, the overall petroleum oil consumption was observed as 58.57, 59.44 and 52.57 for family size of <4, 4-5 and 6-7, respectively. The overall usage of LPG cylinder (1.43 and 1.34) was found in the annual income group of $2,700-$6,700 and $6,700-$13,300, respectively. In the context of family size, the statistics of LPG cylinder consumption observed were 1.07, 1.45 and 2.33 for family size of < 4, 4-5 and 6-7, respectively. An increasing trend was noticed in the consumption of average number of LPG cylinders with the increase in the family size.

The overall usage of LPG cylinders (1.96 and 2.27) was observed in the annual income group of $2,700-$6,700 and $6,700-$13,300, respectively. In the context of family size, the LPG cylinder consumption observed was 1.43, 1.92 and 3.69 for family size of <4, 4-5 and 6-7, respectively. An increasing trend was noticed in the overall usage of LPG cylinders with the increase in the family size.

The overall monthly electricity consumption during summer and winter seasons for small (12) industries was 2.42 million and 2.61 million kWh, respectively. In case of micro industries (2), overall monthly electricity consumption during summer and winter seasons was 0.22 and 0.51MWh, respectively.

Table 4 Average energy consumption pattern of the sampled institutes

Sectors	LPG cylinders during summer (Number)	LPG cylinders during winter (Number)	Annual petroleum oil consumption (litres)	Electricity consumption during Summer (MWh)	Electricity consumption during Winter (MWh)
Hospital	4.00	6.00	2,000	647.5	662.3
Bank	0.00	0.00	0.00	136.3	182.6
Private school	0.00	0.00	0.00	525.0	520.0
Government school	15.00	25.00	0.00	385.0	380.0
Overall	3.25	7.75	2,000	423.4	436.2
Hotel 1	1,050,	1,060	100	90	Hotel 1
Hotel 2	1,575,	1,580	96	86	Hotel 2
Overall	1,312.5	1,320	98	88	Overall

Table 4 revealed that in the hospital, the LPG cylinder usage for summer and winter season was 4 and 6, respectively and for government school the monthly average LPG cylinder usage for summer and winter season was 15 and 25, respectively (used for preparing mid day meal funded by state government). The monthly average electricity consumption during summer and winter season in case of hospital was 647.5 and 662.3 MWh, respectively. The monthly average electricity consumption for summer and winter season for bank was 136.3 and 182.6MWh, respectively. The monthly average electricity consumption for private and government schools was 525.0 MWh and 385.0 MWh, respectively. The overall monthly LPG consumption in intuitional sector was 3.25 and 7.75 cylinders for summer and winter, respectively. The overall annual petroleum oil consumption in the institutions was

2,000 litres. The overall monthly electricity consumption during summer and winters in the institutions was found to be 423.4 and 436.2MWh, respectively.

The overall electricity consumption in Hotel sector during winter and summer season was 1,312.50MWh and 1,320 MWh, respectively and overall LPG consumption during summer and winter season was 98 (Number) and 88 (Number), respectively.

The annual per capita energy consumption in the study area worked out to be 1,484.46 kWh, whereas the per capita energy consumption in India during 2015-16 was 1,075 kWh (MEITY, 2018). The annual per capita carbon dioxide emission n the study area was 1.2 tonnes, whereas the per capita carbon dioxide emission of India was 1.9 tonnes per year (Jos *et al.*, 2016). The per capita carbon dioxide emission in Dharampur block of district Solan was 1.1 tonnes (Kumar, 2015).

The energy consumption and carbon dioxide emission for selected households of study area was 821.0 MWh and 712.59 tonnes, respectively. The energy consumption and carbon dioxide emission for selected industrial, commercial and institutional buildings of study area were 30,658.1MWh and 24,905.06 tonnes, respectively. The total energy consumption from various sectors was 31,479 MWh and carbon emission of 25,617.65 tonnes was emitted in the selected areas.

The estimated energy consumption for domestic and other sectors in Solan city was 58.27 and 287.17 GWh, respectively and estimated carbon dioxide emission in Solan city was 50,541.58 and 0.499 million tonnes respectively, hence total estimated energy consumption was 3.45 million MWh and total carbon dioxide emission calculated was 5.49 million tonnes in Solan city.

To assess the roof top solar power potential of domestic and commercial buildings

The overall average rooftop area under the annual income of $2,700-$6,700 and $6,700-$13,300 was 88.45 and 91.74 m^2, respectively. The increasing family size showed an increasing trend in the rooftop area as 96.29, 101.86 and 111.40 m^2, respectively (Table 5).

Table 5 Average roof top area (m^2) in selected household

Particular	Overall rooftop area	Overall potential rooftop area	Overall rooftop area (meter square)
Annual Income group			
$2,700-$6,700	88.45	66.33	6.63
$6,700-$13,300	91.74	68.80	6.87
Family size (Number)			
<4	96.29	72.22	6.63
4--5	101.86	76.74	6.87
6--7	111.40	83.55	6.63

The average potential rooftop area in the income group of $2,700-$6,700 and $6,700-$13,300 was 66.33 and 68.80 m^2, respectively. The data regarding family size showed the increasing trend of the average potential rooftop area of 72.22, 76.74 and 83.55 m^2 for < 4, 4-5 and 6-7 family size, respectively. The overall average rooftop solar power according to the annual income group of $2,700-$6,700 and $6,700-$13,300 was 6.63 and 6.87 kWh, respectively. The average rooftop solar power showed an increasing trend with increasing family size. The average rooftop solar power was 7.22, 7.67 and 8.35 kWh for the family size of < 4, 4-5 and 6-7, respectively.

Table 6 Total rooftop area (m^2), potential rooftop area (meter square) and rooftop solar power potential (kWh) of selected commercial and institutional buildings

Particulars	Roof top area	Potential rooftop	Rooftop solar potential
Hospital	4,013.96	3,010.47	301.05
Bank	100.0	77.0	7.7
Private school	38,000	34,904.0	3,490.4
Government school	29,000	26,178.0	2,617.8
Overall	17,778.49	16,042.36	1,604.23

Hotel 1	70	52.5	5.25
Hotel 2	47	35.25	3.53
Overall	58.5	43.88	4.39
Small industries	4,416	3312	331.2
Micro industry	56.0	47	4.7
Overall	2,236	1679.5	167.9

Table 6 indicated that the total rooftop solar power of small industries was 331.2 kWh and for micro industries it was 4.7 kWh as the potential rooftop area of small and micro industries was 3,312 and 47 m^2, respectively. The rooftop solar power potential was 301.05, 7.7, 3,490.4 and 2,617.8 kWh for hospital, bank, private school and government school, respectively. The average rooftop solar power potential of Hotel sector in Solan city was 4.39 kWh. The total estimated rooftop solar power potential of Solan city was worked out to be 312.08GWh, which in line with Singh *et al.* (2016) according to which India's installed capacity of solar power was 302.08GWh. The total estimated rooftop power potential for domestic sector was 216.40 GWh and 96 GWh for other sectors, respectively. The per capita rooftop solar power potential worked out to be 0.975 MWh in Solan city. The solar rooftop power potential of Solan city in domestic sector was 69% of the total solar potential of the city, hence proving that the rooftop solar power potential of domestic property is more than 50% of all the sectors of a city put together (Brandt, 2013).

4. CONCLUSION

To meet out energy needs of the population on sustainable basis, we have to increase the efficiency of energy systems, to develop alternate energy systems and to harness the unlimited solar potential. The total energy consumption from various sources in Solan city was 287.17GWh with carbon emission of 0.549 million tonnes. The total roof top solar power potential in Solan city was 312.08GWh. If the total roof top solar power in Solan city is harnessed, it can meet out the energy demand of Solan city.

Conflict of interest

The authors declares that they have no Conflict of interest

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