

Potential for Net Zero Energy Neighbourhoods in the Ahmedabad Urban and Solar Contexts

Janaki Contractor, M.Arch
[Glasgow School of Art]

Filbert Musau, PhD
[Glasgow School of Art]

ABSTRACT

Many net zero buildings have been proposed in different parts of the world. However, there is an argument that an individual building is not the right scale to develop Net Zero Energy Housing. The neighbourhood scale has the potential to integrate not only individual building systems, but also multi-building systems as well as of integrating neighbourhood geometry. This scale also offers opportunities for load sharing between buildings and diversity in functions. In spite of India having a rich solar energy resource, there are no Net Zero Energy Neighbourhoods being developed. This paper tests the potential of three existing neighbourhoods in Ahmedabad, with different building typology and geometry, to achieve Net Zero Energy status by way of retrofitting Photovoltaic Technology. After a review of historical energy bills to assess the energy demand, the PVSyst software package (version 6.0) is used to test the potential performance of solar retrofits in the three different neighbourhoods. The results show that each of the three neighbourhoods can achieve Net Zero Energy status by retrofitting PV Panels. However, the investment cost and payback periods are prohibitive for the economic contexts of the three neighbourhoods. The paper further proposes neighbourhood scale retrofitting strategies. It also proposes government support policies, based on the neighbourhood scale, to overcome the cost limitations in achieving Net Zero Energy status.

INTRODUCTION

Carlisle, Geet and Pless (2009,4) define a Net-Zero Energy Neighbourhood, as “One that has greatly reduced energy needs though efficiency gains such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy”. There are mainly two approaches to achieve a Net Zero Energy Neighbourhood. The first one is designing a neighbourhood considering environmental requirements and providing various technologies to balance the energy use and production. Another approach is providing system retrofits in existing neighbourhoods such that the energy produced by renewable sources is equal to the total energy used in the neighbourhood. Retrofit in building terminology usually refers to introducing new technology for a building to be more efficient. Keirstead and Shah (2013, 47) states that since buildings are long-lasting infrastructure, much of the existing building stock will need to be improved if short and medium-term energy efficiency and greenhouse gas reduction targets are to be met. In addition to the benefits achieved by retrofitting individual buildings, area-wide retrofit schemes can offer further benefits in terms of supply-side

Janaki Contractor is a Masters of Architectural Studies student (Urban Design Pathway) at Glasgow School of Art, Glasgow, UK.
Dr. Filbert Musau is a registered Architect and Lecturer in Environmental Design at the Glasgow School of Art, Glasgow, UK.

technologies, optimisation of area wide availability of renewable sources, economics of scale and project finances. However, financing of neighbourhood-scale and individual retrofits of renewables is currently expensive. Today, this technology is not widely applied due to high cost of implementation and long payback periods. Some examples of the neighbourhood approach include Masdar and Bedzed. Masdar in UAE is proposed as a carbon neutral city planned for 40,000 residents. It aims at sustaining 90% energy demand through Photovoltaic energy, while the rest will be sustained by other renewable sources. Although planned to achieve Net Zero Energy, the parts of it that have been executed have succeeded in some aspects but failed in others. Bedzed, designed as Britain's first net Zero Energy Community, also had failures which include its inability to use renewable resources for the combined heat and power plant; occupants behaviour of adding portable heaters resulting in higher than predicted energy consumption. This paper tests the potential of three existing neighbourhoods in Ahmedabad to achieve Net Zero Energy status by retrofitting PV Technology. The neighbourhoods have different housing typology and geometry.

SOLAR POTENTIAL OF AHMEDABAD FOR RETROFITTING PV PANELS

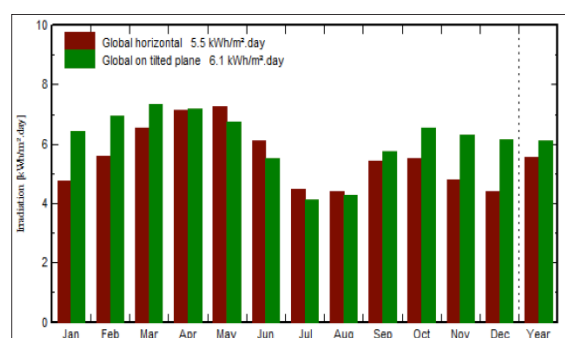


Fig. 1: Solar Irradiation in Ahmedabad based on Pvsyst software simulation. (Source: Authors)

In India, the solar radiation is abundant throughout the year; hence introducing solar photovoltaic technology in existing neighbourhood can reduce non-renewable energy demands. Ahmedabad is situated in the hot semi-arid climate zone of West India and is considered to have summer all year with average temperature of about 27° C to 41° C. It receives high solar radiation (Fig 1) especially in the south direction, hence has high potential for solar energy generation.

For testing the solar potential of the city to achieve a nZEN, a range of Neighbourhoods have been selected according to variation of housing typologies that exist in the city. The first neighbourhood type is the “POL” house – the traditional houses of Ahmedabad, consisting of a number of houses, facing the street and forming a cul-de-sac. Each house is connected to the street by a verandah (semi open space). This study is carried out in “Desai ni pol” situated on the eastern part of Ahmedabad. The second selected neighbourhood type is the apartment, which has grown rapidly in the city due to increased density and land prices. Many different kinds of apartments exist in the city ranging from low cost to luxury apartments with multiple Bedrooms. This study is carried out in Ambawadi apartments located in Western Ahmedabad, in a vicinity of mainly residences with few institution and commercial developments. The neighbourhood has six apartments with a large open space near the entry. Each apartment has three floor levels with four residences on each level. The third selected neighbourhood has the bungalow housing typology, which is spreading fast on the western side of the city due to ample availability of land. Many bungalows exist with large open spaces in the form of gardens with good potential to generate solar energy. However, shading is high in this neighbourhood due to trees. This study is carried out in Rushil bungalows located in western Ahmedabad near SG highway. The neighbourhood has 12 bungalows, each with a garden in the front and a covered backyard.

ENVIRONMENTAL CHARACTERISTICS OF THE SELECTED EXISTING NEIGHBOURHOODS

Pol: Each house has a deep long plot, sharing the longer wall with neighbouring houses, thereby reducing exposure to sun. Dense placements also offer mutual shading to the houses. The courtyard lets the hot air of the house to escape out and allows fresh air to enter. It also provides diffused light to the inner areas of the house. The tripartite windows maintain the inner temperature by allowing the cool breeze to enter and

providing shade from direct sunlight. A rainwater-harvesting tank is also located below the central courtyard which helps cool the temperature of the courtyard.

Ambawadi Apartments: These apartments have low energy demand due to their orientation and planning. The periphery of the each floor has balconies, creating an offset for the main living spaces. Generous overhangs protect the houses from direct sunlight, keeping the houses cooler. Moreover each apartment block offers shading to the other block thereby reducing direct exposure of facades.

Rushil Bungalows: These bungalows have very few environmental considerations in their design. They have few openings with overhangs, providing shade from direct sun. However, most openings are not shaded, exposing the façade to direct solar radiation, and therefore heating the house fast in summer.

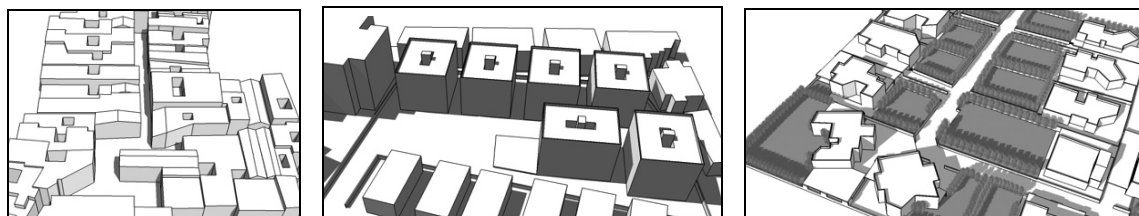


Fig 2: 3D Massing of the selected neighbourhoods of Pol Houses, Ambawadi apartments and Rushil bungalows respectively (Source: Authors)



Fig 3: Photos of Pol Houses, Ambawadi apartments and Rushil bungalows respectively (Source: Authors)

For this study, seasonal variation of metered energy bills for selected houses in each neighbourhood was collected and averaged out to arrive at the energy used per household. The energy used per household was multiplied with the number of houses in the neighbourhood to arrive at the total energy used by the neighbourhood. Table 1 compares the energy consumed in each neighbourhood.

Table 1. Comparison of Energy Consumed [Pol (1), Ambawadi apartment (2), Rushil bungalow (3)]

	1	2	3
Energy / House / Month	270 kWh	525 kWh	1550 kWh
Number of Houses	32	72	12
Average number of Persons/House	6	4	4
Energy in Common Uses	-	-	825 kWh
Energy of Neighbourhood / Month	8640 kWh	37800 kWh	19,425 kWh
Energy of Neighbourhood / Year	103,680 kWh	4,53,600 kWh	2,33,100 kWh
Energy consumed per Person	540 kWh	1575 kWh	4856.25 kWh
Floor area / House	60 Sq. m	75 Sq. m	150 Sq. m

Table 1 shows that Neighbourhoods 1 and 2, which are low and middle income housing respectively, have less floor area and hence less energy used per person, when compared to Neighbourhood 3, which is upper middle class housing. Hence it could be concluded that energy used per person is greatly dependent on floor area of units and the lifestyle of residents in each Neighbourhood. From all three selected neighbourhoods, the Pol has the least energy consumed per person.

nZEN POTENTIAL: SOLAR ENERGY PRODUCTION AND COST

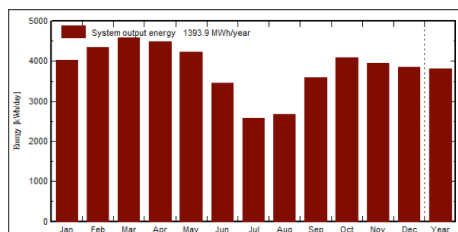


Fig 4 Annual Output of Desai Ni Pol by Pvsyst simulation. (Source: Authors)

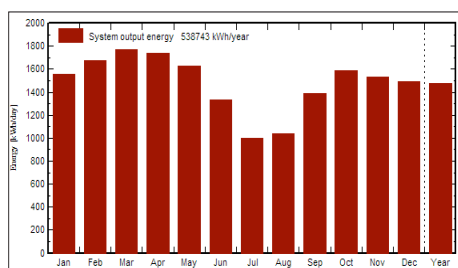


Fig 5 Annual Output of Ambawadi Apts. by Pvsyst simulation. (Source: Authors)

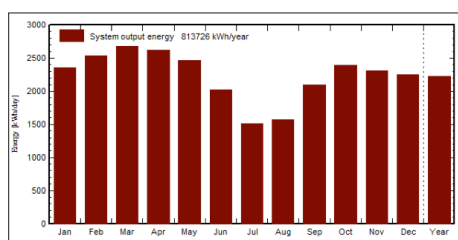


Fig 6. Annual Output of Rushil Bung. by Pvsyst simulation. (Source: Authors)

The shadow studies done in this research suggest that in the Pol house and Ambawadi apartments, the street and the space in between buildings respectively, remains shaded during most of the year, except for noon when the sun is overhead. Similarly in Rushil bungalows the open gardens and main access road remains shaded during most of the day by trees and vegetation.

Hence in all three neighbourhoods, the roof has maximum potential for direct as well as diffused solar radiation. In addition to the roof, the open space in Ambawadi apartments and open gardens and access road in Rushil bungalows have potential for direct and diffused solar radiation respectively. Hence in this study, roof area of all neighbourhoods is considered for solar energy generation.

Table 2 compares the energy produced using monocrystalline panels in each neighbourhood based on available roof area. It suggests that the Energy Produced/Year in Desai Ni Pol and Rushil bungalows, by using entire available roof area, is much more than the requirement of the entire neighbourhood. In Ambawadi apartments, the Energy Produced /Year is almost equal to the requirement of the entire neighbourhood. However, if energy demand increases in future, the neighbourhood can use its open spaces for solar energy production.

Table 2. Comparison of Solar Potential [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Roof Area Available	4916 Sq. m	1800 Sq. m	2900 Sq. m
Open Space	877.5 Sq. m	3335 Sq. m	4075 Sq. m
Plot Coverage	0.85	0.35	0.41
Energy Demand / Year	103,680 kWh	4,53,600 kWh	2,33,100 kWh
Energy Potential /Year (Generated from PVSyst)	14,75,212 kWh	5,40,151 kWh	8,70,243 kWh
Excess Energy Potential	13,71,532 kWh	86,551 kWh	6,37,143 kWh
Potential Output vs. Demand	14: 1	1.2: 1	3.7: 1
Energy Consumed /Person	540 kWh	1575 kWh	4856 kWh

Table 2 suggests that there is a direct relation between plot coverage and the excess energy produced - the lower the plot coverage (Neighbourhood 2 and 3), the lower the excess energy produced. The more compact the neighbourhood with higher plot coverage and less obstructions, the more the excess energy produced. With proper balance of these factors during the initial design stage, one can achieve nZEN. Table 2 also suggests that the full roof potential to produce solar energy for Desai ni pol, Ambawadi apartments and Rushil bungalows is 14, 1.2 and 3.7 times more than the present demand. Hence, all three neighbourhoods have potential to convert into nZEN as well as produce excess energy.

Similarly, Table 3 compares the investment cost of solar energy production in each neighbourhood. It suggests that in Desai ni pol, Ambawadi apartments and Rushil bungalows the cost that each household

would pay annually to achieve nZEN is 2, 1.5 and 1.3 times respectively more compared to the current cost. Also, unit cost of energy increases in all neighbourhoods with retrofitting solar PV.

Table 3. Comparison of Investment and Loan as per Energy Demand of Neighbourhoods [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Present Yearly Cost/ Household	14,400 INR	31,200 INR	1,26,000 INR
Roof Area according to Energy Demand	346 Sq. m.	1515 Sq. m.	780 Sq. m.
Module Cost	33,95,561 INR	122,44,109 INR	63,03,898 INR
Support Cost	25,96,605 INR	113,69,530 INR	58,53,619 INR
Inverter and Wiring	7,98,956 INR	34,98,317 INR	18,01,114 INR
Transport and Mounting	37,04,577 INR	120,72,796 INR	70,98,285 INR
Total Investment /Neighbourhood	104,95,699 INR	391,84,752 INR	210,56,916 INR
Payback Period	22.7 Yrs.	17.4 Yrs.	13.9 Yrs.
Yearly Cost for Neighbourhood after Loan	10,39,780 INR	37,88,168 INR	20,68,237 INR
Yearly Cost/ Household upto 20 Yrs.	32,493 INR	52,613 INR	1,72,353 INR
Unit Cost	10.01 INR/ kWh	8.33 INR/kWh	8.84 INR/kWh

NET ZERO ENERGY BUILDING (nZEB) VS NET ZERO ENERGY NEIGHBOURHOOD (nZEN); COST AND CHALLENGES

Table 4 compares the nZEN approach versus the nZEB approach with respect to cost limitations and the potential energy generation through solar panel retrofits. It shows that taking a neighbourhood approach is much more advantageous, as it provides availability of more shared renewable resources on site and energy sharing between houses thus helping to achieve Net Zero Energy. It provides more solar access with availability of multiple rooftops and common spaces including open space and streets, when compared to individual buildings, hence providing more unshaded potential area for PV installation. The unit cost of energy is also lower in nZEN approach compared to the nZEB.

Table 4. Comparison of Grid Connected nZEB vs. nZEN: Energy Output vs. Cost [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

	1	2	3
Annual Energy Demand / Building	3,240 kWh	75,600 kWh	18,600 kWh
Present Annual Cost / Building	14,400 INR/Yr.	3,74,400 INR/Yr.	1,26,000 INR/Yr
Yearly Investment for nZEB (PVSystem)	50,398 INR/Yr.	7,80,690 INR/Yr.	2,34,137 INR/Yr
Yearly Investment for nZEN/ Building	32,493 INR/Yr.	6,31,361 INR/Yr.	1,72,353 INR/Yr
Unit Cost For nZEB	15.55 INR/kWh	10.33 INR/kWh	12.59 INR/kWh
Unit Cost For nZEN	10.01 INR/kWh	8.33 INR/kWh	8.84 INR/kWh

Table 5: Stand Alone Systems for Individual Buildings Based on Annual Energy Required [Pol (1), Ambawadi Apt (2), Rushil Bungalows (3)]

Infrastructure	1	2	3
Module Cost	1,62,899 INR	3,10,813 INR	7,75,776 INR
Battery Cost	4,73,709 INR	9,04,122 INR	26,43,603 INR
Regulator Cost	82,911 INR	1,30,322 INR	2,77,008 INR
Transport/Fitting	6,21,833 INR	9,77,418 INR	20,77,560 INR
Total Investment	13,41,353 INR	23,22,676 INR	57,73,947 INR
Annuities	1,07,634 INR/Yr	1,86,378 INR/Yr	4,63,316 INR/Yr
Maintenance Cost	1,18,427 INR/Yr	2,26,031 INR/Yr	6,60,901 INR/Yr
Total Yearly Cost/ Household	2,26,061 INR/Yr	4,12,408 INR/Yr	11,24,217 INR/Yr
Unit Cost	69.99 INR/kWh	66.90 INR/kWh	62.27 INR/kWh

Comparing the cost of Stand-alone nZEB (Table 5) with Grid connected Neighbourhood scale retrofits (Table 3); nZEN turns out to be more economically viable. The cost that each household ends up paying annually for a Stand-alone nZEB is about 7-10 times more than that required for an nZEN. This reduced cost in the neighbourhood approach happens because of sharing of infrastructure required for connecting the system to the Grid. The cost of batteries required for storage of excess energy, transport and maintenance is high, as required in Stand-alone systems, acting as a major barrier for nZEB.

Barriers and Challenges

Though connecting to the grid offers incentives of using electricity all year round and selling the excess energy, in India, it faces a few challenges. For an owner, a single point of contact from financing, to operation and maintenance is required for solar PV to be more prominent. However, presence of multiple partners forms a major barrier. Similarly, there might be a problem of ownership in shared rooftops and long-term leasing for solar power generation due to fixed incentives. Moreover, the connection of multiple PV systems to the grid might also have stability issues, hence making it vital to monitor it to avoid its collapse. Also monitoring of energy being fed into the grid to avoid misuses is important. Power generated from other sources if fed into the grid, can lead to a collapse of the feed-in-tariff model. Likewise, availability of different types of devices of diverse quality, for net metering, creates a barrier for precise measure. Hence, establishing a “star rating system” for devices is fundamental for its success. According to the Technology Strategy Board in UK, neighbourhood retrofits also face challenges due to lack of awareness amongst owners about sustainability and long term gains. The biggest challenge to realise this approach is reaching a mutual agreement amongst families within the neighbourhood regarding investing in this technology. Moreover, lack of competition, choice and availability of materials, higher than expected cost are other challenges making it difficult to implement this technology.

COMPARISON OF USING ALTERNATIVE PANEL TYPES

In order to overcome the cost limitation, since monocrystalline panels are the most expensive PV panel, using different panel types might be a useful option for these neighbourhoods to attain Net Zero Energy. Table 6 suggests that in Pol houses and Rushil bungalow, the amount of energy produced by Polycrystalline and Hybrid Panels is enough to meet demand. However, Table 7 indicates that the cost difference is not sufficient when compared to Monocrystalline panels. The cost of energy per unit also increases by using a less efficient panel. Hence, though using an alternate panel type limits the excess energy produced, the cost of its realisation is more compared to the current cost of the neighbourhood.

Table 6: Comparison of Energy Potential by using Alternative Panel types on entire roof area available [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

Panel Type	1:Energy Output	2:Energy Output	3:Energy Output
Energy Demand	1,03,680 kWh	4,53,600 kWh	2,33,100 kWh
Monocrystalline	14,75,212 kWh	5,40,151 kWh	8,70,243 kWh
Polycrystalline	13,83,012 kWh	5,06,392 kWh	8,15,853 kWh
Hybrid	9,22,008 kWh	3,37,594 kWh	5,43,902 kWh

Table 7: Comparison of Unit Cost (INR/kWh) and Yearly Cost (INR/Yr.) using Different Panel Types on entire Roof area Available [Pol (1), Ambawadi apartments (2), Rushil bungalows (3)]

Panel Type	1: INR/ Yr.	1: INR/ kWh	2: INR/Yr	2: INR/ kWh	3: INR/Yr.	3: INR/ kWh
Present Cost	-	2.8 - 4.3	-	2.8 - 4.3	-	2.8 - 4.3
Monocrystalline	111,94,544	7.59	43,10,750	7.98	66,73,778	7.67
Polycrystalline	107,87,085	7.80	41,44,648	8.18	64,19,822	7.87
Hybrid	87,02,963	9.44	32,92,894	9.75	51,18,930	9.41

SOLUTIONS FOR OVERCOMING COST LIMITATIONS

In order to overcome the cost limitations, an important step would be to reduce energy demand by increasing the efficiency of building envelope. Provision of shading devices for openings and use of better insulating materials in walls and roof would help decrease the overall demand of the three neighbourhoods. In addition, provision of neighbourhood scale retrofits like using efficient streetlights, offering better transportation networks, reducing energy required in pumping ground water, etc. would further help reduce the energy demand of the neighbourhood. After reducing the demand, below are few

other ways, which would help overcome the cost limitations of neighbourhood retrofits.

1) Selling the Excess energy to the Government

In each of the three Neighbourhoods, the roof area available has potential to produce excess energy. If the excess energy could be fed into the grid and sold to the government, the payback period and cost could be reduced to a large extent. The State already has a number of privately owned power plants, which sell energy to the state government. According to the Gujarat Electricity Regulatory Commission (GERC) the current rate of buying solar power for all PV Plants commissioned between 1st April 2014 to 31st March 2015 is reduced to 8.03 INR. If each of these neighbourhoods sells their excess energy to the government at the given rate, the yearly instalment would reduce to a large extent. For example in the Pol, yearly instalment on the loan, for the demand energy roof area, would be 32,493 INR. However, after entire roof area installation and selling of excess of energy the neighbourhood has to pay 5660 INR/Yr. (Table 8). Table 8 shows the reduced price that each neighbourhood has to pay after selling excess energy to the government. Hence, in this way major part of the investment amount could be borne by the government, while the residents could pay the remaining amount. However, there are some barriers in this approach – the main one being convincing the government to invest in the neighbourhoods.

Table 8: Selling Excess Energy to the Government [Pol (1), Ambawadi Apts (2), Rushil Bunglows (3)]

	1	2	3
Annual Excess Energy	13,71,532 kWh	86,551 kWh	6,37,143 kWh
Money Received by selling Annual Excess Energy at Rs 8.03/kWh	110,13,401 INR/Yr.	6,95,004 INR/Yr.	51,16,258 INR/Yr.
Yearly Cost / Neighbourhood	111,94,544 INR/Yr.	43,10,750 INR/Yr.	66,73,778 INR/Yr.
Yearly Cost/ Neighbourhood (After selling Excess Energy)	1,81,143 INR/Yr.	36,15,746 INR/Yr.	15,57,520 INR/Yr.
Yearly Cost/ Household (After selling Excess Energy)	5660 INR	50,218 INR	1,29,793 INR
Present Yearly Cost/ Household	14,400 INR	31,200 INR	1,26,000 INR

2) Public Private and Neighbourhood Partnership

Currently few retrofitting strategies have been established in India to promote solar power generation in the domestic context. In Gujarat, the city of Gandhinagar has been promoted as the first solar city, where they aim to produce 5MW of energy through public and private rooftops. The city has tried the Public Private Partnership concept, wherein the private developers would be given access to rooftops of 25 public buildings and around 250 private houses. City dwellers would be given a “green incentive” of INR 3/kWh of energy produced on their privately owned rooftops after Solar PV installations. This serves as a useful strategy of combining private and public investors to invest in solar power generation on local rooftops. However, since this strategy is limited to individual buildings, the roof area available is less giving no neighbourhoods scale energy benefits to house owners. Regarding neighbourhood scale retrofitting strategies, this approach should prioritise installations at the neighbourhood rooftops that are most exposed to solar radiation and should distribute such solar exposure benefits to all dwellings across the neighbourhood. A phased installation approach would potentially help low-income dwellers to distribute capital installation costs for longer periods, thus reducing their monthly repayments.

3) Government Policies, Initiatives and Incentives

Many countries have tried to promote and fund retrofits within the government policies. For example, the UK Government’s “Green Deal plan” is a financing mechanism that allows consumers to repay through saving on energy bills for energy saving home installations. Even within India, the Jawaharlal Nehru Nation Solar Mission is an important initiative by the government to promote solar power wherein it targets at producing 20,000 MW of grid connected solar power by 2022. Under the mission, private companies are offered incentives to invest in solar power, by reducing customs duty on solar PV by 5% and exempting excise duty on Solar PV. This is expected to reduce the overall cost of a rooftop solar

panel installation by 15–20%. The government also provides Generation based incentives (GBI) and 80% accelerated depreciation income tax benefits on solar energy production. Moreover, the Ministry of New and Renewable Energy (MNRE) in India provides 30% subsidy on the cost of installation of solar PV power plant in all states. However, existing policies target large-scale production of solar power plants and not the domestic sector. Hence, more policies are required, targeting urban neighbourhoods, providing incentives directly to the residents, and helping them achieve Net Zero Energy.

CONCLUSIONS

From the research, it can be concluded that all three neighbourhoods in Ahmedabad have immense potential to produce solar energy and achieve nZEN status. This paper has tested the initial potential of the neighbourhoods and provided rough estimates of investment. The key limitation of this technology is the cost factor and methods have been suggested to overcome this within the solar and economic context of Ahmedabad. With a proper mix of environmental considerations at a design stage- considering orientation, plot coverage and density of a neighbourhood, the energy demand can be restricted. This, followed by government support to implement this technology, by either buying excess power from local neighbourhoods instead of private power plants, or by offering incentives to private and public investors for investing in it at the neighbourhood scale, would help each of these urban neighbourhoods in Ahmedabad to achieve Net Zero Energy. The work suggests that further research is needed to explore links between plot coverage and solar energy in Ahmedabad in order to inform policy on neighbourhood planning to benefit from the conflicting requirements of solar exposure and shading. Further work is also needed on cost reduction strategies to make solar PV more accessible to low income neighbourhoods.

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