Environmental Sustainability Impacts of Solar Energy Generation on Domestic Greenhouse Gas Emissions in a New Zealand Neighbourhood

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Synopsis: Solar energy, a renewable resource, is constantly replenished by natural processes and can be used by humans more or less indefinitely. This paper quantifies the potential measure of solar energy that could be generated from the roofs of the built-up areas of an existing urban neighbourhood at Glen Innes, Auckland, selected for a case study. It examines how solar energy can contribute towards total domestic energy requirements of households for two scenarios. It also explores possibilities of enhanced potential solar contributions for the hypothetical case with minimal possible changes in roof configurations for Glen Innes. The outcomes suggest that for the maximum use (Scenario 1) of available solar efficient roof area, the residential roof-top potential in terms of percentage contributions of total domestic demands (except space conditioning) could increase from 73% to 82.5%, and the same for a realistic situation (Scenario 2) could be enhanced from 46% to 69% with minimal changes in roof configurations for the selected case study site. The correct orientations of building roofs make significant contributions to reducing CO2 emissions at local scale.

Keywords: solar energy generation; solar panels; residential roof top potential; solar water heater; photovoltaic modules; roof orientation; environmental sustainability.

1 Introduction

New Zealand's commitment under the Kyoto Protocol is to reduce greenhouse gas emissions to 1990 average levels over the period 2008 to 2012 and to take financial responsibility for any emissions above this level if the target is not achieved (New Zealand Climate Change Office 2006). This presents potential opportunities for the growth of renewable energy options such as solar and wind power. The New Zealand solar water heating industry has grown more that 40% in the last 3 years, and the EECA (Energy Efficiency and Conservation Authority) has anticipated that the development of distributed renewable generation will play an increasingly important role in future energy supply (Ministry for Environment (MfE) 2005a: 284).

In 2004, New Zealand residential sector energy demand, with the exception of domestic transport, was 62.5 petajoules (Ministry of Economic Development 2004: 7), and this sector also consumed 34.3% of the total electricity generated (Ministry of Economic Development 2006: 27). Space and water heating are the predominant uses of energy in New Zealand houses (EECA 2001: 1; MfE 2005: 66). In total, New Zealand currently emits 8.1 tons of carbon dioxide per capita (Ministry of Economic Development 2006: 33). An average New Zealand household emits about 450 kg of CO_2 per year from an average electricity use of 6700 kWh/year and about 460 kg of CO_2 per year from 2400 kWh/ year of average gas use (NIWA Science 2006). HEEP (Household Energy End-use Project) studies over three locations, Auckland, Hamilton and Wellington, showed that hot water accounts for about 29.0% of the total household energy use (HEEP 2003, Year 7) and is the main source of CO_2 emissions (NIWA Science 2006).

Solar water heating produces zero net emissions of greenhouse gases; it is renewable, natural, abundant and could be easily integrated with existing building water heating systems. If a solar heating system is correctly installed, it could supply up to 50–75% of annual domestic water heating energy demands.

Two major regions in the forefront of solar technology are Australia and Western Europe. Availability of solar radiation in New Zealand (1400-1500 Kwh/m²) is at par with Melbourne (1472.7 Kwh/m²) and above European levels (Germany at 1002.5 Kwh/m²), thus making future prospects of solar technology in New

Zealand very attractive (EECA 2001: 14; Solar Industries Association 2006: 2-3). Solar radiation can be utilized either as heat (e.g. solar hot water systems) or as electricity (through photovoltaic –PV systems). 'Solarization', the concept of mass retrofitting of roof, wall and floor insulation, draught proofing and solar water heaters to existing buildings, could achieve large greenhouse gas reductions (Blakers 2006). An average house roof of 150 m² receives around 220 000 KWh per year, more than 20 to 30 times the house's total requirements. "*The total household rooftop area in New Zealand is exposed to primary solar energy that is equivalent to about twice the total national energy consumed*" (EECA 2001: 10*).* National climate change policies focus on greenhouse gas emissions from major sources such as agriculture, electricity generation and road transport (MfE 2005b: 13). "*Solar thermal is often not included in national energy policy targets because it is a heat technology and can most successfully be implemented at the local level* " (EECA and SIA 2002: 2).

This paper focuses on quantifying the potential contribution of solar energy collected at the local scale from the roofs of an existing urban neighbourhood in Glen Innes, Auckland, selected as a case study site. The potential residential rooftop contributions towards total domestic energy requirements of households are calculated for two scenarios. This paper also examines the possibilities of enhanced potential solar contributions for the hypothetical case with improved roof configurations. Carbon dioxide mitigations or savings that could be achieved are also calculated and compared.

2 National and International Examples

In countries such as the United Kingdom, Germany, the Netherlands, Denmark and Ireland, there has been considerable examination of the potential of solar energy use in domestic purposes. Table 1 presents a comparison of some selected national and international examples.

Table 1: Comparisons of National and International Solar Projects

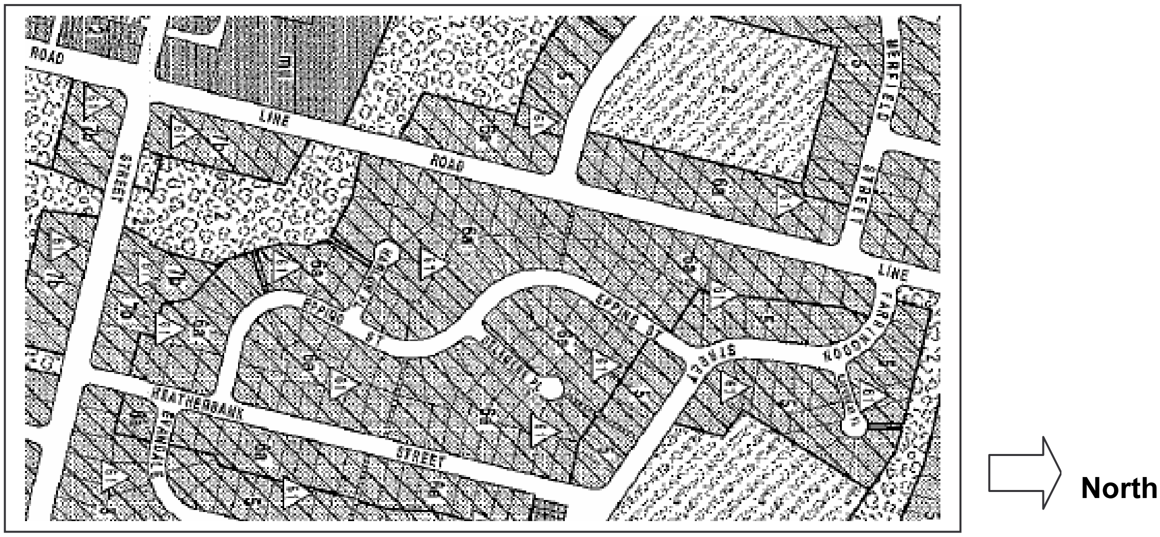
Projects	**Climatic Data** degree days, annual mean temperature	**Descriptions**	**Solar Technology and System**	**Actual Solar Performance**
Skotteparken, Ballerup, Denmark	3400 degree days (base 18ºC); 7.8º C	Apartments housing 100 families	Six solar heating systems 100 m² each; 6 m² solar panel/apartment; district heating network	382 KWh/m² including saved network losses; decrease in heat demand by 50% compared to conventional housing;
"Blixembosch 2" and "Driehoeksbos" Meerhoven, Eindhoven, Netherlands	2750 degree days (base 18ºC); 10.9º C	New residential developments; "Blixembosch 2"(1600 dwellings) and "Driehoeksbos" (400 dwellings)	Two 2.75 m² solar collectors /standard roof; 476 installations in two sites; local district heating system;	330 kg CO_2 reduction; decrease in heat demand by 50%;
South Wiggenhausen-Süd solar development, Friedrichshafen, Germany	3717 degree days (base 17ºC); 9.7º C	570 houses	Individual modules for solar collectors range from 7.5 m² to 12.5 m²; 4,300m² of solar collectors;	Will supply 50% of space heating and hot water requirements;
Hockerton Housing project, Hockerton, Nottinghamshire, UK	3344 degree days (base 18ºC); 9.4º C	5 Single storey earth sheltered terrace dwellings and a study centre on 10 ha site	7.65 kW array of photovoltaics plus two 5 kW wind turbines, all grid-connected and passive solar gain from south-facing conservatories;	The renewable energy system provides all the energy for the houses, which are designed to minimise energy demand.
2 Hauraki Road, Waiheke Island, Auckland, NZ	1150 heating degree days (base 18ºC); 15.3 º C	total floor area of 196 m^2	315 litres insulated solar hot water cylinder;	supplying well over 90% of hot water demand
20 Karaka Road, Waiheke Island, Auckland, NZ	1150 heating degree days (base 18ºC); 15.3 º C	91m^2 three bedroom house	PV system 4.4 kW peak and consists of 36 panels (each 120 Watts at 12 volts DC) in two strings	first year of operation the PV system generated 5300 kWh/annum

Source: European Commission Directorate-General for Energy and Transport – http://www.managenergy.net/indexes/I38.htm; http://www.worldclimate.com/; Shannon et al, 2003; IDMP- http://idmp.entpe.fr/stations/nzl03/nzl03.html; Vale et al. 2006; Vale and Vale 2000; Twinn 2003.

The Australian '*Solar Cities'* programme, a vision for the future, has received significant government support for trials of solar technologies and energy efficiency in urban areas, specifically in existing and new residential and commercial buildings and will run from 2004/05 to 2012/13 (Australian Government 2006).

3 Glen Innes – The Case Study Site

Glen Innes is a low-density, low-rise, typical NZ suburb with detached large single households in a medium-density zoning according to the operative Auckland District Plan 1999. The styles of the buildings relate generally to the 1950s and are predominantly single storey houses. A significant part of the housing stock is state housing. The case study site is bounded by Heatherbank Street towards the east, Line Road in the west, Farringdon Street towards the north and Taniwha Street in the south. According to census data for 2001, the Glen Innes site has a population of 648, a calculated average household size of 3.8 for the six mesh blocks contained within the site, and 171 total privately occupied dwellings (Statistics New Zealand 2001). Fig 1 presents the Glen Innes case study site.



(Source: Auckland District Plan Operative 1999, Isthmus Section)

Fig 1: Glen Innes Case Study Area

3.1 Auckland City: Growth Management Strategy and Glen Innes into the Future

The *Auckland City: Growth Management Strategy*, a vision for the future of the city adopted by the Auckland City Council in December 2003, sets a broad strategic direction for urban development within the city to manage growth in a sustainable way. This growth management strategy also takes into account the policy outcomes of future regional growth according to the recommendations from the *Auckland Regional Growth Strategy 1999*.

"In tandem with the decisions being made at the regional level about growth patterns, public transport development and land use. Auckland City has developed "Auckland City: Growth Management Strategy (December 2003)" to provide a strategic framework to accommodate this expected growth on the Isthmus over the next 50 years" (Auckland City Council 2003: 2).

This strategy has identified two areas of growth: areas of stability (which are not suitable for increased growth) and areas of change (where increased growth can be supported). The planning for growth in areas of change is further classified into three categories of priority centres: priority 1 centres (growth is already underway 2003/04 onwards); priority 2 centres (growth will start as required); and priority 3 centres (in areas which would require infrastructure upgrades for growth uptake) (Auckland City Council 2003: 3). Auckland City has introduced the Residential 8 zone into the Isthmus District Plan to achieve the outcomes of the City's adopted growth management strategy that became operative on 2004.

After extensive community consultation with the local community and stakeholders of Glen Innes, Auckland City has developed a liveable community plan, “Glen Innes into the future”, which was adopted on 22 July 2004 by the Council. This provides a framework for managing growth and development in the area over the next 20 years. A key action identified within this strategy is to introduce the Residential 8 zoning following public consultation that allows more medium- to high-density housing such as town houses, terraced housing, and apartments that are in close walking distance of Glen Innes town centre and public transport (Auckland City Council, Section 32 Report, Plan change 61: 2). The key principles proposed to guide the future development of Glen Innes include: environmental protection; location of growth; integrated development; strong communities; urban design; economic development and employment and funding (Auckland City Council 2004).

3.1 Auckland City Council Plan Change 61 in Glen Innes

Auckland City is undergoing a plan change process, plan change 61 in Glen Innes. The Council had publicly notified the plan change in 2005 and the hearing of submissions was held in June 2006. Under the Resource Management Act 1991 the Council has obligations and functions to undertake, in particular evaluation of the proposed plan change before the notification of a change to a District Plan. Auckland City Council’s Section 32 Report analysed four proposed changes and considered they were an effective method of achieving the regional and City Council growth management objectives (Auckland City Council, Section 32 Report: 15). This public plan change 61 had proposed zoning changes for residential areas generally located within a 5-minute walk of the Glen Innes town centre and mainly fronting onto the arterial roads in the area – Apirana Avenue, Line Road, Taniwha Street, and Point England Road (Auckland City Council, Section 32 Report, Plan change 61: 3). The selected case study site in Glen Innes for this paper fulfills these criteria and the main changes proposed were to rezone the case study site from Residential 6a medium intensity zoning partly to Residential 8b and partly to Residential 8a. This indicates the Council believes this area is most likely to accommodate significant future growth. The Residential 8a zone allows a residential density up to one unit per 150 m^2 and a maximum height of 11.0 m, while the Residential 8b zone permits a higher residential density up to one unit per 100m^2 and a maximum height of 14.0 m.

In spite of having a medium density zoning according to the Auckland District Plan Operative 1999, the case study site does not currently accommodate sufficient houses to become eligible as a medium-density housing area and is predominantly a low-density residential area. Summary of submissions indicates many of the residents do not support rezoning options for Glen Innes (Auckland City Council 2005).

3.3 Why Glen Innes has been selected?

According to the *Auckland City: Growth Management Strategy,* Glen Innes has been listed as one of the priority one centres for both residential growth and business development. Urban form changes are already occurring rapidly in this area.

“Glen Innes is identified as a Priority 1 “area of change” in Auckland City’s growth management strategy because it has the following characteristics:

- *good access to Central Auckland and to Manukau by road and rail;*
- *a growing population, which is expected to grow by about 3,000 people or 900 new homes within the next 20 years;*
- *well established community and town centre;*
- *availability of some vacant or underdeveloped residential and business sites and*
- *natural features and open spaces”*(Auckland City Council 2004: 9).

Apirana Avenue, a regional arterial road, and Taniwha Street, a district arterial road, run through Glen Innes Road in addition to the collector street, Line Road. Glen Innes is also located at a moderate distance from Auckland central business district (CBD). The town centre has an excellent combination of public transport (train route connecting the city and other suburbs of Auckland, bus terminal), shopping centre, business activity areas, open space areas, special purpose activity areas, and residential areas ranging from Residential 5 to Residential 8 surround all these activities. The forthcoming local urban form transformations in Glen Innes provide a useful research focus to understand such issues as local environmental sustainability in relation to various attributes, land uses, zoning, forms of urban development such as smart growth, transit oriented development (TOD), new urbanism characteristics, urban design and ecological qualities. The future redevelopment provides an opportunity to incorporate more potential for sustainability.

4 Methodology

4.1 Existing Domestic Energy Demand Calculation

As a first component of the research discussed above, the total existing demands of household energy use in water heating, space heating, cooking, refrigeration, lighting, entertainment, etc., are separately estimated from the calculated data on per capita national requirements based on overall energy use from the Ministry of Economic Development 2004 data for the Glen Innes case study area. The HEEP study (2003) suggests there is no statistically significant difference in average household energy use between HEEP houses in Auckland, Hamilton, Wellington and Christchurch. Improved estimates of household appliance energy use have been prepared showing that over the three locations and considering electricity and gas household energy end use, hot water accounts for about 29%, space conditioning 22%, lighting about 11%, refrigeration about 10%, cooking about 8% including range, entertainment 3%, and others, unassigned and largely miscellaneous, about 17% of the total (BRANZ 2003: YEAR 7, Executive Summary: ii.). Comparison of data from EECA and Centre for Advanced Engineering (CAE) sources indicate water heating was 36% and space heating was 38% of total domestic energy use in 1995 for all types of energy including geothermal (CAE 1997: 48; EECA Energy End Use Database 1995). Total domestic energy use on a national scale has risen from 52.9 PJ for the year 1995 (EECA 2000a, Table C7: 112) to 56.8PJ in 2001 (Ministry of Economic Development 2004: 7).

Water heating energy could be contributed largely by roof-mounted solar water heating panels. The energy generated by photovoltaic (PV) arrays mounted on the appropriate roof areas should be used for those functions that require electricity, such as entertainment, lighting, refrigeration and others, rather than using the electricity for space conditioning. Though cooking could be also done by gas, it has been assumed that 49% of the energy requirements for household use, except water heating and space conditioning (BRANZ 2003: ii), will be from electricity. Table 2 presents existing household energy demands calculated in different categories. Excluding space conditioning, in all other categories the total energy use of the Glen Innes case study area is 7837 GJ per annum. Space heating is excluded from analysis from this point because it does not need to be provided by electricity.

Table 2: Existing Demands of Household Energy Use

Data HEEP, Year 7	% Contributions	Existing Demands (GJ/ annum)
Water Heating	29.0%	2914
Space Conditioning	22.0%	2210
Cooking	8%	804
Entertainment	3%	301
Lighting	11%	1105
Refrigeration	10%	1005
others, unassigned and large miscellaneous	17%	1708
Total	-	10047

Source: HEEP, Year 7 2003

4.2 Potential on site solar energy generation based on current building roof orientations

4.2.1 Building Roof Areas and Solar Efficient Roof Areas Estimation

From aerial photographs, and using a spatial methodology developed previously (Ghosh 2004), total building roof areas of the Glen Innes case study area are calculated. The total site area is 15.5 hectares. The value of total building roof areas is equal to 2.3 hectares and 15.1% of the total site area. Considering the slope of the roofs and an orientation of roof within 45 degrees on either side of north as solar efficient (Breuer *et al.* 1994), the total available solar efficient roof areas currently available were drawn diagrammatically on the roof forms and calculated spatially (Ghosh 2004). It is estimated that 0.61 hectares or 6143 m² of the total roof area is solar efficient. Solar efficient roof areas that would be shaded by the trees are not included in the calculations. Fig 2 presents building roof areas and solar efficient roof areas of the Glen Innes case study site.

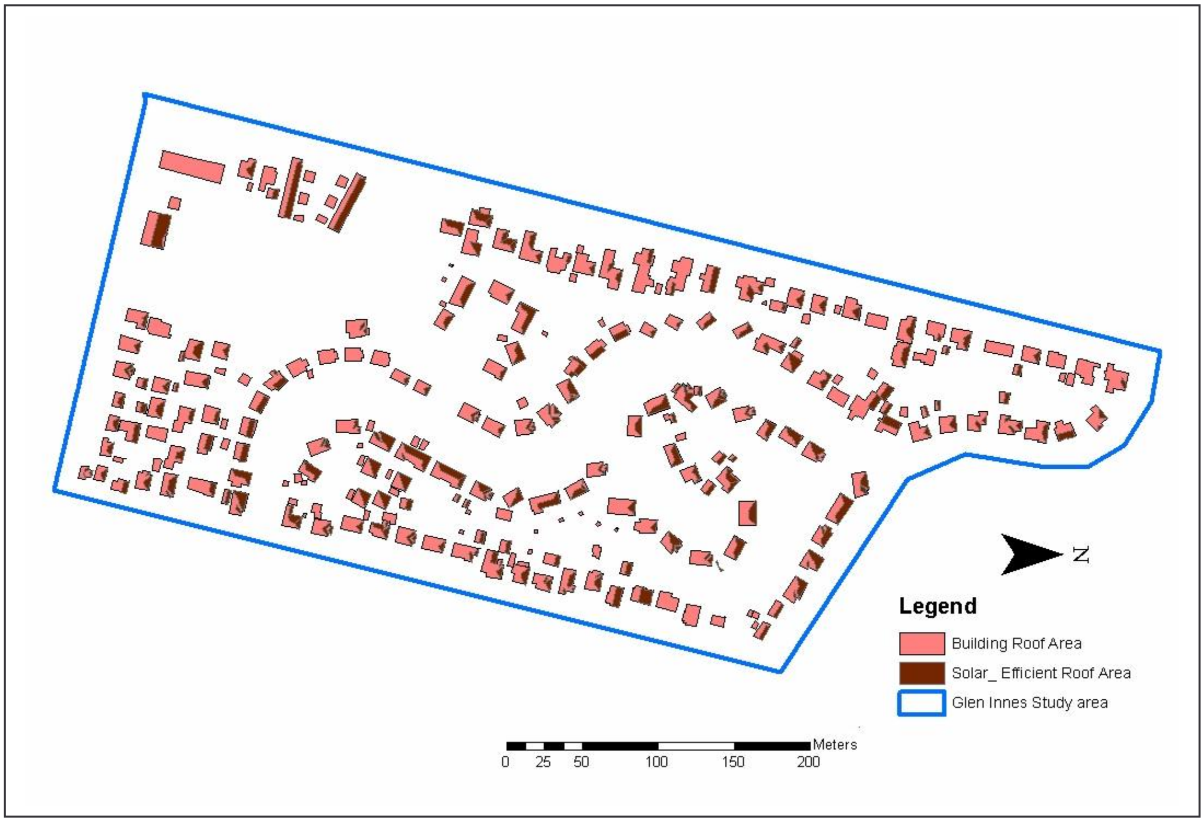


Fig 2: Glen Innes Building Roof Area and Solar Efficient Roof Area

There are different categories of building roof areas comprising large, medium and small houses, garages, stores and shades. Two categories, large roof areas ranging from 60 m² to above 200 m² and smaller roof areas below 60 m², are considered. Each category has four sub-categories. The analysis in Table 2 indicates that in the large roof areas category, the dominating group of building roof areas are between 100 and 149.99 m² and that 27.5% of the total roof areas of these buildings are solar efficient.

Table 2: Building roof area wise Available Solar Efficient Roof Areas

Category As per Building Roof Area (m²)	Numbers	Total Building Roof Area	Total Solar Efficient Roof Area	Average %
Large Roof Areas				
60-99.99	24	1902	527	27.7
100-149.99	102	12462	3428	27.5
150-199.99	20	3412	877	25.7
Above 200	11	3150.7	902.7	28.6
TOTAL 1	**157**	**20927**	**5735**	**27.4**
Small Roof Areas				
1-19.99	32	379.4	43.7	11.5
20-29.99	29	705.47	52.2	7.4
30-49.99	23	485.02	104.21	21.5
50-59.99	9	907.7	207.68	22.9
TOTAL 2	**93**	**2477.5**	**407.8**	**16.5**
TOTAL(TOTAL 1 + TOTAL 2)	**250**	**23404.3**	**6142.7**	**26.2**

Roof areas below 20 m² dominate smaller roof areas, which may be garages and shades. Only 16.5% of the total smaller roof areas are solar efficient. Considering large and smaller roof areas, overall 26.2% of the total building roof areas in the Glen Innes site are currently solar efficient.

4.2.2 Energy potential of Current Solar Efficient Roof Areas

A recent study by the UK Department of Trade and Industry (2006) proposed that so-called 'micro-generation' (small-scale renewable energy systems such as solar panels on houses) could generate 30 to 40% of the country's total electricity demand by 2050. Micro generation can provide both hot water and electricity. For hot water provision, the Sola60TM H300 Collector is designed to provide hot water for a family of six and has a 4.5 m² solar collector area and a 270 litres storage tank (CAE 1996: 186). It is therefore assumed that a 4 m² per household solar water heater area would be sufficient on average for all sizes of household and this would need to be placed on part of the solar efficient roof area (Ghosh 2004: 85). Energy generation from each 4 m² solar water heater is at the rate of 2200 Kwh (CAE 1996: 186). or 7.92 GJ per annum. For electricity, 50 m² of photovoltaic modules can generate100 MJ /day, assuming 10% efficiency in Auckland and 1 m² generates 2 MJ per day (Redshaw and Dawber 1996) or 0.73 GJ per year (Ghosh 2004: 126).

As the roof design of buildings could incorporate varying slopes and roof patterns, it is very important to determine how many of these solar efficient roof areas are useful. Solar water heaters or photovoltaic modules are generally in the form of rectangular panels, therefore, when placed on the roof of buildings they do not adequately cover all the solar efficient roof areas which have triangular edges, shorter lengths and different shapes. These various roof configurations affect the utilization of solar energy from solar efficient roof areas.

Considering two scenarios based on current available solar efficient roof areas, this paper examines solar efficient roof utilization: full or 100% utilization irrespective of roof configurations (Scenario 1) and partial utilization considering roof configurations (Scenario 2).

Under Scenario 1, all the solar efficient roof areas available are assumed to be utilized fully for solar hot water panels at the rate of 4 m² per household, and the remaining area is allocated to photovoltaic modules. The corresponding energy equivalents in GJ/annum and % of the total existing demands that could be provided in water heating and other categories except space conditioning are calculated. The results indicate that 5714 GJ/annum and 73% of the total existing demands (except space conditioning) could be provided by the currently available solar efficient roof area.

In Scenario 2, two solar water panels, 1 m X 2 m, equivalent to 4 m² per household, are fitted on the solar efficient residential rooftops of the dwellings in Glen Innes using ArcGIS. Only 158 out of 171 dwellings could accommodate two solar water heater panels on their solar efficient roofs; one could accommodate one panel; and 12 buildings do not have appropriate solar orientations.

Similarly, photovoltaic modules of 0.6 m X 1.2 m were fitted on the area of solar efficient roofs remaining after placing solar hot water panels. This process was time-consuming and so was carried out for only 60 dwellings in the Glen Innes site. The realistic available areas of photovoltaics were compared with total available solar efficient roof areas for those 60 dwellings. The calculations show that these buildings realistically could use only 58% of the total available solar efficient roof areas, and 42% solar efficient roof areas would be lost due to inappropriate roof designs (mostly hips and valleys). The percentage value of 58% obtained for photovoltaics in combination with solar water heater provisions was then applied to achieve overall results for the complete Glen Innes site. The corresponding energy equivalent in GJ/annum or % of the total existing demands that could be provided in water heating and other categories (except space conditioning) is calculated.

The results indicate that 3588 GJ/annum and 46% of the total existing demands except space conditioning could be provided by solar energy collected from the existing rooftops.

Table 3: Two Scenarios on Available Solar Roof Area Utilizations

Scenario 1		Scenario 2	
Total available solar efficient roof area (m2)	6143	**Total available solar efficient roof area (m^2)**	6143
Total area (m2) of solar water heater required @ 4 m^2 per household	984	**Total area (m2) of solar water heater utilized @ 4 m^2 (2 no 1 m X 2 m solar panels)per household**	634
Remaining Area for photovoltaic (m^2)	5159	**Area utilized for photovoltaic considering 58% use (m^2)**	3195
Energy equivalent water heater (GJ/annum)	1948	**Energy equivalent water heater (GJ/annum)**	1255
Energy equivalent photovoltaic (GJ/annum)	3766	**Energy equivalent photovoltaic (GJ/annum)**	2332
Total onsite solar energy generation (GJ/annum)	5714	**Total onsite solar energy generation (GJ/annum)**	3588
Total onsite CO2 emission Savings (tonnes/annum)	1029	**Total onsite CO2 emission Savings (tones/annum)**	646
% of existing demands except space conditioning category	73%	**% of existing demands except space conditioning category**	46%
Unused solar efficient roof area (m^2)	0	**Unused solar efficient roof area (m^2)**	2314
% of unused solar efficient roof area(m^2)	0	**% of unused solar efficient roof area(m^2)**	38
Energy equivalent unused solar efficient roof area	0	**Energy equivalent unused solar efficient roof area**	1689

Camilleri and Jaques (2001) have assumed that new macro-scale hydroelectricity projects are overburdened with public opposition and all new large-scale electrical capacity in NZ will therefore come from thermal sources (mainly coal) at a greenhouse gas cost of 0.64 kilograms of equivalent CO_2 emissions per kilowatt hour of electricity (Camilleri and Jaques 2001). The recent cancellation of Project Aqua supports the idea that this assumption of no new macro-scale hydroelectricity generation is currently valid and that all new generation from increased usage or any new reduction in usage will either increase or reduce the amount of thermal electricity demand in New Zealand, thus this figure of 0.64 kilograms CO_2 per kWh (0.18 tonnes per GJ) will be used in the carbon dioxide calculations here. The results for Scenarios 1 and 2 and corresponding CO_2 values of domestic energy savings are calculated and presented in Table 3.

4.3 Additional Solar Efficient Roof Generation

In Glen Innes hip roof patterns currently predominate on single detached houses. Gable roofs provide more rectangular roof area in one plane compared with hip roofs and could provide a useful increase in useful solar efficient roof area.

Considering only minimal change to roof configuration, such as using gable end roofs rather than hip roof into a gable end roof, additional solar efficient roof area that could be generated is calculated. The results are presented in Table 4.

The outcomes suggest that for the maximum use (Scenario 1) of available solar efficient roof area, the residential rooftop potential could increase from 73% to 82.5% in terms of percentage contributions of total domestic demands (except space conditioning). For a more realistic situation (Scenario 2) this use could be enhanced from 46% to 69% with minimal changes in existing roof configurations for the selected case study site.

Solar energy generation from minimal changes in roof configurations will save 1164 tonnes of Co2 from Glen Innes per year in Scenario 1 and 901 tonnes of Co2 from Glen Innes per year in Scenario 2.

Table 4: Additional Solar Efficient Roof Generation assuming gable roofs

Total additional available solar efficient Roof area (m2)	1034
SCENARIO – 1	
Assuming these additional solar efficient areas for photovoltaics & 100% use, energy equivalent of photovoltaic (GJ/annum)	755
Total onsite solar energy generation (GJ/annum) (Scenario 1+ Additional)	6469
Total onsite CO2 emission Savings (tonnes /annum) (Scenario 1+ Additional)	1164
% of existing demands except space conditioning category	82.5%
SCENARIO – 2	
Total additional area (m2) utilized that was lost in Scenario 2	2314
Grand Total of the above two areas(Scenario 2+ Additional)	3348
Assuming this area is for photovoltaics & 58% use, energy equivalent photovoltaic (GJ/annum)	1418
Total onsite solar energy generation (GJ/annum) (Scenario 2+ Additional)	5005
Total onsite CO2 emission Savings (tonnes /annum) (Scenario 2+ Additional)	901
% of existing demands except space conditioning category	69%

5 Conclusions

At local scale, roof forms and orientations of buildings have a considerable impact on solar energy generation. This study establishes that appropriately designed (i.e. rectangular) roof forms are able to enhance solar energy generation from roofs, allowing appropriate solar hot water and photovoltaic panel installations with minimal change. It is clear that it is very important to make provision for the future installation of solar panels at the conceptual stage of roof design in any new buildings that may be proposed in the future intensification of development in Glen Innes. Building such roofs can make significant contribution to generating energy on site, with the potential to provide up to 80% of household electricity demand in the case study site, and can also reduce production of CO_2 emissions. The carbon dioxide reduction of about 900 tonnes for the case study area represents 1.4 tonnes per person. If this strategy was adopted for all residential areas it would deliver a significant reduction of 17% of New Zealand's total CO_2 emissions. The social barriers and economic calculations for the uptake of solar technologies have not been included in this study. Future research should undertake studies of these dimensions to present an integrated research focus on renewable solar energy generation from residential roofs to design more self-sufficient neighborhoods.

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