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Assessing potential for reduction in carbon emissions in a multi-unit of residential development in Sydney

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Abstract

There is an increase in the construction of multi-unit residential buildings around inner Sydney in the past few years. The energy consumption in Australia has increased by approximately 30% and associated carbon dioxide emissions. This research examines a large multi-unit residential case study located close to the Sydney's Central Business District (CBD). Current energy consumption for the common areas such as the basement, car parks, lobbies, etc. and water usage for gardens are estimated using the actual data on electricity and water usage. Potential for reduction in energy consumption and their equivalent carbon footprint values are examined. Three carbon emissions reduction strategies include: savings from electricity generation from roof solar PV installation; rainwater harvesting from the roof and minimising annual water loss by evaporation in swimming pools reducing energy demand for water supply. In addition, carbon benefits provided by the trees are calculated using an urban forest assessment tool. Recommendations suggest that installation of solar PV on the roof, using an appropriate swimming pool cover, rainwater harvesting and a better tree canopy cover collectively could improve the overall CO_2 footprint performance of the selected case study.

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Keywords: Sustainability; CO_2 emissions; residential development; energy efficiency; carbon footprints

1. Introduction

One of the important worldwide concerns is the increased energy consumption resulting from a larger amount of CO_2 emissions in recent decades. International Panel on Climate Change (IPCC) in 2014 estimated global carbon

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emissions from fossil fuels have significantly increased about 90% from 1970 to 2011 [1]. The rapidly growing trend of world's energy consumption has already raised concerns about sustained energy supply over time [2, 3, 4, 5]. Furthermore, due to significant combustion of fossil energy resources, notable environmental impacts, such as emissions of greenhouse gases (GHG), depletion of ozone layer, global warming, and climate change effects are clearly visible [6,7,8]. Some scholars believe these impacts are not only effectively decreasing the quality of human life which is one of the most serious and irreversible global impacts but also likely to affect at inter- and intra-generational levels so that future generations could face a shortage of supply of energy and resources [9]. Therefore, minimising worldwide energy consumption and promoting consumption in a sustainable manner are important. The concerns about depletion of finite resources on the earth parallel to the demand for energy and its consequent environmental, ecological and health impacts of fossil fuel are continually growing in Australia similar to the rest of the world. Renewable energy has contributed to approximately 6% of Australian's energy production and the primary energy consumption in Australia (by 94%) is from fossil fuels [10]. Australia's energy usage and production of GHG emissions share is about 68% of total GHG emissions and is expected to grow to 72% by 2020 [11]. Buildings contribute to a larger share of national and global GHG emissions. Data from ABARES indicated that in 1990, the residential sector contributed 43.4 mega tonnes of CO_2 emissions. It is predicted the emissions would increase by 28.6% and would be equal to 55.8 mega tonnes of CO_2 emissions by 2050 [12].

Energy-related CO_2 emissions can be reduced by designing energy consumption reduction strategies during the design stage. However, considering that new dwellings only contribute about 2% of the housing stock, against 98% of inefficient existing dwellings, it justifies the importance of any energy efficiency improvements to the existing housing stocks on GHG emissions and demand for fossil fuels. As one of the most popular energy generators "solar photovoltaic (PV) technology" is one in which energy is directly generated from sunlight. Australia receives an average of seven hours of sunshine per day. Australia has a great potential for solar energy generation as an alternative source of energy [13].

Findings from a study regarding the consumption of energy in multi-unit residential developments in Inner Sydney confirmed that despite low energy consumption expected in multi-unit residential buildings, per capita energy consumption and subsequent GHG emissions is comparatively greater than detached dwellings [14]. Inefficient energy consumption is especially common in areas such as parking and common areas lighting, pool heating. Therefore, there is a huge potential for saving energy at a community scale.

In regards to the importance of sustainable development, this paper selected and examined a large multi-dwelling residential estate as a case study in an eastern suburb of Sydney, located approximately eight kilometres from Sydney's Central Business District (CBD) and analysed how energy-related CO_2 emissions could be successfully reduced in an existing multi-unit residential development.

2. Aims and objectives of this research

The aims of this paper are to measure current energy use for common areas, water consumption for gardens and swimming pools and carbon benefits provided by the onsite trees in an existing multi-unit residential case study and explore sustainable and effective strategies to reduce energy-related CO_2 emissions. The main objectives of this paper follow.

- To measure current energy use and equivalent CO_2 emissions generated from the common areas;
- To measure current evaporative loss of water from swimming pool and water consumption for the gardens;
- To estimate energy and CO_2 emission reduction potential of onsite renewable electricity generation from roof solar PV installation;
- To measure the water demand that could be generated from building roof rainwater harvesting and its equivalent CO_2 footprints reduction from reticulated supply for gardens; and
- To calculate annual carbon sequestration rate and storage potential of onsite tree canopy cover.

3. Methodology

In recent years the multi-unit residential developments are on the rise close to Sydney CBD. A multi-unit residential development located close to Sydney CBD in Australia was selected as a case study for this research.

This specific type of development is selected because formulating effective energy and CO_2 emissions reduction strategies at this community scale, larger than an individual building scale, could be very useful to contribute cumulatively to the reduction in community scale energy use and CO_2 emissions.

Four different methods were applied in this paper to explore and integrate the carbon performance of this multi-unit residential development.

Data on actual electrical energy, and water usage for common areas, gardens were collected from water and energy bills for a particular time period of three years. Energy consumption data in common areas is in the form of electricity use for heating and lighting in the basement car parks, gym areas, lobbies and garbage collection and disposal spaces. Estimation of equivalent values of energy-related CO_2 emissions was then determined. Similarly, water consumption data for garden and relevant data for the swimming pool was collected and water use estimated.

Then onsite renewable electrical energy generation potential using solar PV installation on the building roofs was calculated. The costs for solar technologies and payback periods were analysed to ensure that these sustainability practices could deliver long-term energy benefits for the community living in the multi-unit development. The technologies for maintaining swimming pool comfort level and heat loss prevention through evaporation were calculated, and equivalent values of CO_2 emissions reduction potential were determined. The roof rainwater harvesting from available building roof areas and storing strategies in different size rainwater tanks on the ground were explored to understand utilisation potential of available rainwater throughout the year.

In this paper, ‘i-Tree Canopy’ tool was applied to measure the annual carbon sequestration rate and gross carbon storage benefits provided by the onsite trees. The ‘i-Tree Canopy’ tool was developed by United States (US) Forest Service in collaboration with Davey, Arbor Day Foundation, Society of Municipal Arborists (SMA), International Society of Arboriculture (ISA) and Casey Trees [15].

Recommendations were developed for incorporating renewable technologies and innovative practices within multiunit residential developments to reduce its overall carbon footprint values.

4. Results

4.1. Use of energy and solar energy potential for common areas

A total of three years’ electricity consumption data were collected from actual energy usage bills and analysed for the base buildings. These buildings include common areas inside and outside the buildings, basement carpark and tennis court. No heating and cooling required for these base buildings and no gas connections are available in these areas.

Figures 1 and 2 below demonstrate electricity consumption and GHG emissions and were presented on a monthly basis for the three-year period. These figures reveal downward trends in a similar pattern for the electricity consumption and GHG emissions in the past three years, but there was a slight upward trend for the GHG emissions at the end of 2014. The downward trend for electricity consumption is likely related to the replacement of more energy efficient light fittings in the common areas since 2014. The figures did not demonstrate seasonal variations in the records as electricity consumption is mainly for providing lighting in the base buildings.

The electricity consumption and GHG emissions were presented in an aggregated format in Table 1. The estate consumed approximately 690-790 kWh electricity and emitted approximate 1 tonnes of GHG per day for the past three years. Based on the monthly energy consumption an investigation was undertaken to explore potential and opportunities for renewable energy sources to offset the electricity consumption from the national grid.

There were two possible renewable energy sources for the estate: small-scale windmill and PV panels. Installing a windmill would require council approval, depend on adequate wind flow to operate efficiently within a medium to high-density urban areas and could also raise occupants’ concerns for the aesthetic appearance and noise produced during its operation. Therefore, the windmill option was removed from the investigation, and only renewable solar generation option was considered.

It is calculated that a 10KW solar system could generate on average 40kWh per day and up to 14,600 kWh annually [16]. The module size of a PV panel varies depending on the manufacturer’s specification. It was estimated

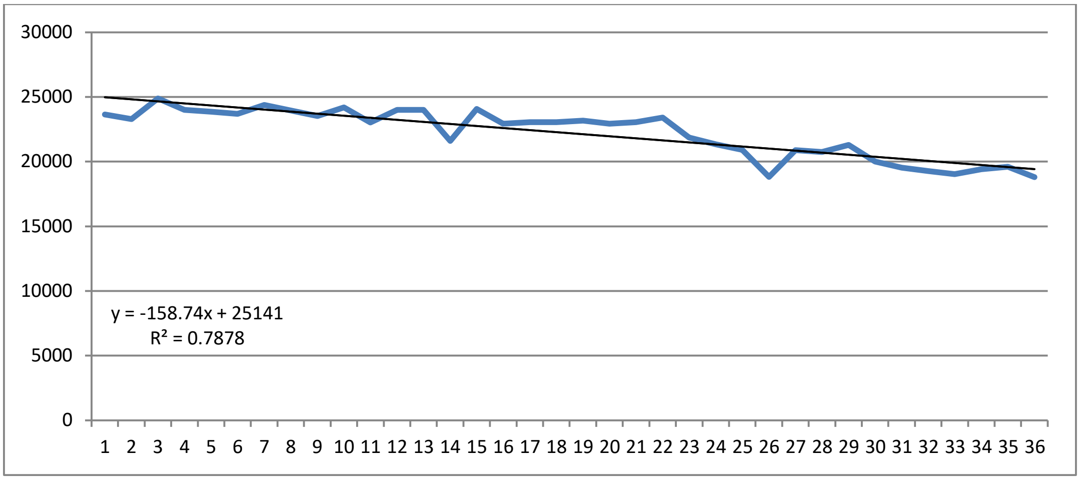

Fig.1. Monthly electricity consumption for three years (Source: Prepared by author).

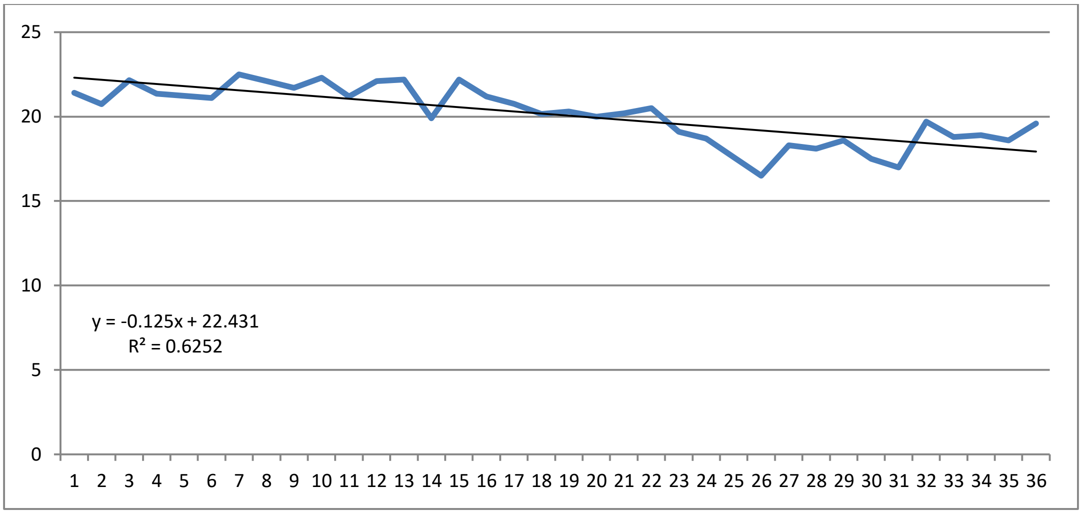

Fig.2. Monthly GHG emissions for three years (Source: Prepared by author).

Table 1. Annual averages from three years electricity consumption and equivalent GHG emissions.

Annual averages from three years data	Electricity consumption (kWh)	GHG emissions (tonnes)
Total	27,1700	241
Monthly average	22642	20
Daily average	744	1

Source: Prepared by author

that a 10KW solar system would require approximately 72m^2 of roof area. The GIS analysis of the roof areas indicated that excluding the roof area allocated for rainwater harvesting in Section 4.2, a total roof area of 768.3m^2 would be available. Based on the analysis approximately 40% (310m^2) of the roof area is solar efficient for the installation. Out of this solar efficient area, approximately 59% (183m^2) is oriented towards north which is ideal for maximising solar gain for electricity generation. There is plenty of roof space available for solar installation. The estate will require approximately an average annual electricity consumption of 271,700 kWh (745 kWh per day).

Therefore, to be self-sufficient in generating electricity for the common area, the estate will require 186 kW solar systems which turned out to be uneconomic for the high start-up cost and not enough roof area for the installation. Therefore, the target solar system should focus on a more affordable 10kW to offset approximately 5% of the electricity requirement for the common area. A 10kW solar system that generates 40kWh per day will reduce approximately 37kg of GHG emissions per day and will reduce 13,505 kg of GHG emissions annually.

Currently, the Federal Government offers financial incentives for solar power systems in two schemes: the Small-scale Technology Certificates (STCs) and feed-in tariff incentives. These incentives allow residential buildings to reduce the upfront construction costs of PV system. Firstly, STCs are in the form of an electronic currency which is equivalent to one megawatt-hour of electricity generated by solar PV system, and the STCs can be traded in the market. Secondly, feed-in tariffs are related to the electricity generated by the PV system, and extra electricity will be exported back to the grid. The total cost is approximately $15,000 (including STCs subsidy) to install 10 kW solar panels based on the current market prices. An investment decision is based on net present value analysis (NPV) and payback period using the following NPV formula:

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \dots\dots\dots\dots\dots\dots\dots (1)$$

Where, C_t = net cash flow expected at time period t
n = project life span
r = selected discount rate and t the time of the cash flow.

The analysis was undertaken on a life span of 15 years at a discount rate of 5%. The initial calculation was based on current energy rates of $0.25/kWh for an approximately of 14,600 kWh electricity generated by 10kW solar panels for the construction cost of $15,000. The NPV was positive of $22,886 and a payback period of just over 4 years.

4.2. Water consumption for garden use and roof rain water harvesting potential

Total water demand for gardens in this development was calculated based on the actual water consumption data for three years. The total annual consumption was calculated to be equal to 13,765 kilolitres (kL). A GIS analysis using georeferenced aerial photographs had calculated that total of 2726 sq. m of building roof area was available for roof rainwater harvesting on site. Assuming 20% of this available roof area would not qualify for rainwater collection as these areas would be lost due to various reasons such as corner areas, inaccessible, unsuitable shape and size, difficulty to connect some of the roof areas to rainwater tanks on the ground and others. Assuming only 80% of the roof would be usable for rainwater harvesting, 2180 sq. m of roof area could be considered for roof rain water collection. Using the following formula [17], approximate annual roof rainwater collection potential was calculated.

$$\sum_{n=1}^{i} R_v = \sum_{n=1}^{i} R_b \times C_1 \times (A_r/1000) - \sum_{n=1}^{i} R_b \times (F_f/1000) \dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots (2)$$

Where, Rv is total roof rain water collection volume in cubic metres; R_b is total building roof areas in square metres; i is the total number of building roof areas in the development; A_r is the mean annual rainfall data in millimetres for the time period 2009-2014 for Sydney [18]; F_f is the amount of water required for first flush diverters and is equal to 0.2 litres/m² [17] and C_1 is the constant equal to 0.9 and assumes that 10% collected rain water loss due to evapotranspiration [17

Considering annual average rainfall data for Sydney, the rainwater collection potential is estimated to be equal to 2268 kL (kilolitres) from the roof of the buildings in the selected development. This volume of rainwater harvested from roof could supply only 16.5% of significantly high current total annual water demand. This demand includes water required for swimming pool and gardens. However, the amount of rainwater harvested from roof needs to be stored in rainwater tanks for use. It is possible that even if the rainwater falls on the roof, due lack of storage spaces, a part of this rainwater could overflow. This overflow volume of water would not be used for supplying the water demand of this development, and the potential to supply water would decrease further. Thus, it depends on the volume and efficiency of rainwater tanks to store and supply water in a timely manner.

Four annual rainwater tank availability scenarios were compared to evaluate the efficient use of roof-harvested rainwater potential. Four scenarios examined were: (a) Scenario 1: 25,000 litres rainwater tank capacity; (b) Scenario 2: 50,000 litres rainwater tank capacity; (c) Scenario 3: 75,000 litres rainwater tank capacity and (d) Scenario 4: 200,000 litres rainwater tank capacity. These scenarios were analysed using 'Tankulator', an online tool developed by Alternative Technology Association (ATA), Australia [19]. The daily water demand of this community for common areas was calculated to be equal to 38kL or 38000 litres, and the water cost was approximately around \$80.00 per day. Based on research data it is assumed that 35% of the total water use at a household scale is for garden use [20]. In this development, it is calculated that 13,300 L of water was required daily for only garden use. In the first stage, it is assumed that only 35% of this daily volume or 4,655 L/day would be supplied by the onsite rain tanks. Two factors considered were that mains water or reticulated supply is connected to the site and plumbing connections to the rainwater tank are only for garden use.

The annual availabilities of rain tank water and carbon dioxide equivalent in four scenarios were measured and compared in Table 2. It is calculated that for potable water supply an equivalent of 0.173 $CO_{2tonnes\text{-}e}$ (Carbon dioxide equivalent) is generated per mega litre (ML) ($tCO_{2\text{-}e}$/ML) consumed [21]. The rainwater utilised for watering the gardens from the rainwater tank saves the consumption of potable water from the reticulated supply.

Table 2. Water consumption and CO_2 emissions for garden use and roof rainwater harvesting potential.

Rain tank Measures	Scenario 1 (25,000L rainwater tank)	Scenario 2 (50,000L rainwater tank)	Scenario 3 (75,000L rainwater tank)	Scenario 4 (200,000L rainwater tank)
Total annual roof rainwater harvesting potential (Litres (L))	2,268,000	2,268,000	2,268,000	2,268,000
Tank size (each)	25,000 L	50,000 L	75,000 L	200,000 L
Total daily garden water use calculated (L/day)	13,300	13,300	13,300	13,300
Total daily water from rain tank for gardens (L/day)	4665	4655	4655	4655
Number of days/year water available & % of days	194 (53%)	241 (66%)	261 (72%)	299 (82%)
Number of days/year tank water overflows (days)	29	15	8	0
Volume of rain water overflow per year (L/year)	490,377	271,075	176,164	0
Equiv. CO_2 emissions tank overflow/year (kg $CO_{2\text{-}e}$)	84.8	46.9	30.5	0
Rainwater tank water used per year (L/year)	900,910	1,120,212	1,215,123	1,391,287
Equivalent CO_2 emissions reduced from reticulated water supply (kg $CO_{2\text{-}e}$)	155.9	193.8	210.2	240.7
Water required from mains supply per year (L/year)	798,165	578,863	483,952	307,788
Number of days the tank is empty and % of days/year	171 (47%)	124 (34%)	104 (28%)	66 (18%)

Source: Prepared by author

The potential rainwater use from rainwater tank was multiplied with the correlated value of water consumption in $CO_{2\text{-}e}$ to estimate total $tCO_{2\text{-}e}$/ML savings. The equivalent CO_2 emissions reduced by using rainwater supply from rainwater tank for garden use were 155.9kg $CO_{2\text{-}e}$, 193.8kg $CO_{2\text{-}e}$, 210.2 kg $CO_{2\text{-}e}$ and kg 240.7 kg$CO_{2\text{-}e}$ in scenarios 1, 2, 3 and 4 respectively. Similarly, the volumes of rainwater that would overflow from the rain tanks were multiplied with the equivalent CO_2 value to calculate the total $tCO_{2\text{-}e}$/ML savings that were lost due to rainwater tank overflows. The equivalent CO_2 emissions reduction potential lost from due to rain tank overflow were equal to 84.8 kg $CO_{2\text{-}e}$, 46.9 kg $CO_{2\text{-}e}$, 30.5 kg $CO_{2\text{-}e}$ and kg 0.0 kg$CO_{2\text{-}e}$ in scenarios 1, 2, 3 and 4 respectively.

4.3 Evaporative water loss reduction potential of a swimming pool

The comfort factor of swimming pool is mostly based on water temperature [22]. American National Red Cross

(2009) indicates the best-appropriated water temperature in a swimming pool is 25.6 °C, and 26°C was adopted for this case study [23]. Water temperature in a swimming pool highly depends on the total heat loss from, and total heat gain by, the water [24]. In other words, the exact heat demand to stable the water temperature in 26 °C depends not only on heating the water but also on preventing heat loss from the water.

According to US Department of Energy (DOE) (2016), in a swimming pool heat loss takes place 70% by evaporation, 20% by radiation and 10% by conduction and convection [25]. However, some solutions can easily help to maintain the water temperature. An appropriate insulation could reduce the heat loss by conduction through pool walls and windbreaks, or pool cover could minimise the convectional heat loss through wind [26]. Pool blanket could improve radiation effects, and both pool blanket and an enclosure could provide a significant reduction in heat loss through evaporation [27]. A pool cover with good thermal properties would also stop heat losses through the fabric. Outdoor pools can absorb 75% to 85% of the solar energy striking on the pool surface and allow significant heat gain by the pool water [25, 28]. It is noted that pool cover is a useful solution as it could provide the decrease in heat losses from conduction, convection, radiation, and evaporation.

The outdoor unheated and unshaded pool covers a total area of 70sqm. The total water loss by evaporation from the unheated swimming pool was estimated to be equal to 98,000 litres annually considering the value that 1400mm or 1400 litres of water evaporate per square metre of the pool area per year in Sydney [29]. A thermal pool cover could save up to 95% of the water lost by evaporation. The water evaporation savings by a thermal pool cover was calculated to be 93,100 litres of water considering 1330 mm or 1330 litres water loss per square meter per year of pool area in Sydney. As the pool water used is of potable quality, the savings of water from evaporative loss by the pool cover is also saved from reticulated supply of water. Using the value of 0.173 CO_2tonnes-e required per megalitre of potable water supply [21], annual equivalent CO_2 emissions reduced by evaporative water loss savings from the swimming pool was calculated. All the values of calculation are presented in Table 3.

Table 3. Average annual water loss and CO_2 savings of water savings from the case study swimming pool.

Location	Annual evaporation loss of water (millimetres/year)	Annual water loss by evaporation from a 70sqm unheated pool (litres/year)	Annual evaporation loss savings by thermal pool cover (millimetres/year)	Annual water savings from a 70sqm pool by a thermal pool cover (litres/year)	Annual equivalent CO_2 emissions reduced by water savings (kg $CO_{2\text{-}e}$/year)
Sydney	1400	98,000	1330	93,100	16.1

Source: Calculated by the author based on [29]

The application of a 'Solar Pool Blanket' would heat the un-shaded outdoor pool by up to 8°C using solar energy directly and would not need to use nearly as much energy. This is because the water would be comparatively warmer, to begin with, and already insulated to prevent heat loss. Also with a pool blanket, the usual pool swimming season could extend (Table 4). Table 4 predicted the efficiency of using a pool cover for heat savings [18, 30].

Table 4. Extension of swimming season by using a pool solar cover (temperatures in degree centigrade).

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
No blanket	24.3	23.5	22.8	19.0	15.1	12.3	11.9	13.7	16.9	20.2	22.6	23.7
With blanket	29.9	28.2	27.4	22.3	17.8	14.6	14.5	17.0	21.1	25.6	28.7	29.5
	+3.9	+2.2	+1.4	-3.7	-11.8				-4.9	0.4	+2.7	+3.5

Source: Calculated by the author based on data from [18, 30].

4.4. Carbon sequestration and storage benefits provided by the onsite trees

The case study covers 10,091 square metres or slightly more than one hectare of land area with a high dwelling density of 100 dwellings per hectare. The site has many large trees distributed within and along the boundary of the development. These trees are capable of providing positive environmental benefits and carbon emission reduction capabilities. Observations from site visit confirmed that the trees have higher leaf density; large heights and some of these trees are located close to the buildings and thus, shade the buildings and facilitate residential energy savings and reduced carbon emissions in addition to potential carbon sequestration and storage benefits by trees.

In this part of this research, 'i-Tree Canopy' tool (http://www.itreetools.org/) was applied [15]. A total of 500 land cover identification points within a smaller site was used to achieve a better statistical accuracy in estimation. At this community scale, current tree canopy covered 18.2% of the total site. Generally, multi-unit residential development typologies have compact structures and are considered to have a comparatively higher density patterns. It was estimated that in the case study, buildings covered 43% of the site; 13.6% of the site had permeable surfaces or grass cover, and the total areas impervious surfaces were up to 18.8% of the site in this multi-unit development. A total of 2177 kilograms (kg) of carbon dioxide was sequestered annually by the onsite tree canopy cover. Onsite trees cumulatively stored 46,393 kg of biomass. Table 5 outlines the outcomes of i-Tree Canopy analysis.

Table 5. Carbon sequestration and storage benefits from onsite trees.

Total site area (m^2)	Onsite total tree canopy cover (m^2)	Onsite total tree canopy cover (% of total site)	Total annual carbon sequestration by the tree canopy cover (kg/year)	Total carbon storage in onsite trees as biomass (kg)
10,091	1837	18.2%	2177	46,393

Source: Prepared by author

4.5. The potential of different carbon emission reduction strategies

Multiple sustainability factors were considered for this analysis. The potential of different energy, water and green infrastructure and carbon emission reduction strategies were measured and analysed. Table 6 presents the potential of carbon emission reduction strategies estimated for the selected case study in this paper.

Table 6. The potential of carbon emission reduction strategies.

Carbon emission reduction parameter		Carbon emission reduction potential
Annual GHG emission reduction by solar energy generation from 10kW Roof Solar PV System installation (kg/year)		13,505
Annual Equivalent CO_2 emissions reduced from rainwater supply (kg CO_{2-e}/year)	25,000L rainwater tank	155.9
	50,000L rainwater tank	193.8
	75,000L rainwater tank	210.2
	200,000L rainwater tank	240.7
Annual equivalent CO_2 emissions reduced by water savings using thermal swimming pool cover (kg CO_2-e/year)		16.1
Annual total annual carbon sequestration by the tree canopy cover (kg/year)		2177
Total carbon storage in onsite trees as biomass (kg)		46,393

Source: Prepared by authors.

Results establish that these strategies can make meaningful contributions towards improving the sustainability performance of this multi-unit residential development.

5. Recommendations and conclusions

As demonstrated in this study, solar PV installation on the roof could generate energy to offset a proportion of electricity consumption from the grid. However, for the current installation cost, it is yet to be economical to be self-sufficient in electricity production from solar power for the estate. The government provides incentives for the use of renewable energy but it is not sufficient to impact on the market prices. This is the first attempt for community scale study in the use of renewable energy, and the impact will be tremendous in terms of reducing GHG emissions if more similar estates can consider generating electricity from renewable sources. In addition, the supply and demand will regulate the installation cost of the solar system to be more affordable. Rainwater harvesting potential of the roofs could supply a reasonable share of water demand for gardens. As compared in four scenarios, the water efficiency from rain will depend on the potential of the site to accommodate appropriate size rain tanks on-site. Saving water reduces CO_2 emissions generated by the reticulated supply of water and also saves potable water as the valuable and limited resource. The results also indicate that there is a potential of reducing evaporation loss of water and associated CO_2 emissions from the swimming pool. As investigated in this study, using an appropriate thermal swimming pool cover can significantly minimise energy demand and water loss through evaporation from the outdoor swimming pool. In a multi-residential development, spaces could be available for integrating suitable green infrastructure elements such as trees which could provide carbon benefits through carbon storage and sequestration. This demonstrates that it is possible to calculate carbon benefits of trees at this community scale. The methodology developed in this paper remains valid for similar developments in Sydney as well as in other cities of the world using suitable substitution of data.

Based on findings from this study, it is recommended that sustainability performance of a multi-unit development should be estimated at a site scale taking unified impacts different sustainability factors into account. Equally important are sustainable energy and water practices applied in common areas in the base buildings, as well as in the areas under private ownerships such as apartments, and also in its public realm such as gardens, lawns, paths and swimming pools, etc. The inclusion of all these factors in the sustainability performance assessment could generate better realistic solutions and positive contributions in retrofitting existing and designing new efficient multi-unit residential developments.

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