# Carbon Neutral Settlements: The role of solar energy

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## Abstract

Solar energy has a major role in moving towards carbon neutral settlements. Three different Australian settlement types are included in this research: urban villages, remote indigenous settlements and isolated mine site camps. This study contributes to a broader ARC research program by Curtin University and Murdoch University on Decarbonising Cities and Regions. A six-element model for carbon neutral human settlements was developed. This was subsequently upgraded to include food as a separate element. The process to achieve a carbon neutral settlement via an emissions reduction plan, following a life cycle analysis, was proposed in six steps. It was found that this planning method can enable new urban developments to achieve a ‘zero energy development’ but achieving a carbon neutral status would require additional measures that address the complete lifecycle of the development. Monitoring and data collection systems were installed in a minesite camp and the data used in a new modelling tool to evaluate different renewable energy systems to offset total lifecycle emissions. These systems were found to only reduce emissions below that of the existing gas-fired power generation somewhere between 2013 and 2018 when costs are expected to drop significantly. In the case of remote indigenous settlements the elements of this planning model were used to identify opportunities for sustainable livelihoods linked to renewable energy in the new carbon economy.

***Keywords:*** *Carbon neutral, urban village, behaviour change, energy efficiency, renewable energy*

## 1. Introduction

The imperative to reduce atmospheric carbon is well documented and one significant area of production is from the built environment. Not only is this carbon produced from the operation of buildings and associated infrastructure, research indicates that a significant proportion is produced during the process of construction and from the production of the materials, the embodied energy. In addition transport, food production, water and waste services are also responsible for increasing the carbon produced. The total of all this carbon has been described as the carbon footprint. Measuring this and reducing it to zero is the substance of ongoing research by the authors (Anda *et al.*, 2010).

The authors developed a six-element model for carbon neutral human settlements. This was subsequently upgraded to include food as a separate element. The carbon content model is comprised of the following:

a. The GHG embodied in the materials of the buildings and the infrastructure;

b. The GHG emitted during the construction process with different approaches;

c. The electrical power and natural gas used in the buildings for different building types;

d. The transport fuels used in the construction and the on-going use by residents;

e. The GHG embodied in the food consumed by the residents;

f. The GHG produced in the full water cycle; and

g. The GHG from the solid waste.

Three cases typical of Australia have been analysed with this carbon content model and six-step reduction process: the urban village, the remote minesite camp and the remote Aboriginal settlement. While the overarching goal in all three cases is to develop a carbon reduction plan to achieve neutrality, as well as an accreditation process, there is also a slightly different research focus in each case. For urban villages, application of 'green infrastructure'; for minesite camps, digital monitoring and control systems; and for Aboriginal settlements, sustainable livelihoods.

The authors subsequently developed a mechanism to help drive innovation and emission reduction (Anda *et al.*, 2011). It is proposed that human settlements around the world can reduce their carbon footprint to zero by engaging in a six-step process as follows:

1. Understanding energy use
2. Behaviour change within people's lifestyles ('curtailment actions')
3. Energy efficiency improvements (retrofits or product upgrades)
4. Monitoring and control ('smart grid' or home area network)
5. Renewable energy (RE) technologies
6. Biosequestration as a sink for the balance of past, current and ongoing emissions.

The order of the six steps above is oriented towards an existing settlement. For new developments, behaviour change programs would need to be implemented later in post-occupancy phases. By producing a surplus to current energy consumption in the last two actions above over a period of time it will be possible to compensate for the historical carbon emissions and return the global atmosphere back to an acceptable point of equilibrium for the natural carbon cycle and to a point where global warming can be reversed.

## 2. Methodology

A literature review was undertaken to determine the methodology best suited to analyse the proposed carbon model of settlements. This was conducted in conjunction with a review of available tools to assess the seven elements in the model. Data collection methods to populate the model include interviews with service providers, surveys with communities and mine sites, an online monitoring system in a remote minesite village, and a proposed active research method with a remote Aboriginal community.

An extensive review of software tools was undertaken to evaluate the functionality available to assess the six elements of the model (Beatty *et al.*, 2011). The evaluation comprised a literature review to identify software tools designed to assess settlements, an evaluation of the software's ability to calculate carbon emissions related to each of the six elements and a pilot test of two to determine their appropriateness for urban, mining and remote Indigenous settlements. The review found that there are only a few software tools that provide the required functionality and none of them fully satisfied all elements.

At first it was decided to use HOMER to assess the potential of renewable energy (RE) as a carbon emission offset solution for mine site villages. As an internationally recognised energy modelling software it is used to assess and size hybrid power systems. However, HOMER is designed essentially to model stand-alone systems and not systems connected to an alternative power system or grid as in the case study. It was decided, therefore, to design an Excel spreadsheet to acquire the appropriate economic RE mix for the case study village. This spreadsheet is referred to as REMAX$^{©}$. Furthermore HOMER is not designed to model two configurations of generation at the same time, one meeting 80% of demand (for example) and another 20% of the load. REMAX is based on the same principles as HOMER but can be modified to suit any load configuration. It is important to mention that this study is only focused on the village and does not include the mine operation.

For new urban developments the Urban Development Institute of Australia (UDIA) has developed the *Envirodevelopment* scheme comprised of six elements, or 'leaves' on a branch, of environmental performance: Ecosystems, Waste, Materials, Energy, Water, Community. In the Energy Element there is a requirement for a 20% reduction in GHG emissions beyond business as usual (BAU). A spreadsheet was developed by the authors to model different mixes of housing thermal performance (star ratings), energy efficient appliances, rooftop solar power systems and other strategies.

## 7. Results

Some preliminary results from the above methods are presented for: the urban village, the remote minesite camp and the remote Aboriginal settlement.

### Solar Energy for the Urban Village

The literature review revealed annual GHG emissions data available for Perth, Western Australia (SMEC, 2008) across six out of the seven elements as per Table 1:

**Table 1:** Annualised GHG Emissions for Perth Across the Seven Elements

| **Emission Source** | **Perth Emissions** | |
|---|---|---|
| | Proportion (%) | Household (t $CO_2$-e) |
| 1. Materials - Embodied Energy | **14** | 3.99 |
| 2. Construction Energy | Not determined | Not determined |
| 3. Operating Energy (Stationary) | **16** | 4.36 |
| 4. Transport Energy | **38** | 10.73 |
| 5. Food - Embodied Energy | **27** | 7.72 |
| 6. Water & Sewer | **2** | 0.45 |
| 7. Solid Waste | **3** | 1.03 |
| Gross Emissions | **100** | 28.17 |

In a separate study related to this work, the author determined that a typical neighbourhood of Perth households of 100 people (approx 40 households) consume food from their supermarket with a carbon footprint of approx 300 tonnes pa and this correlates closely with the figure for item 5 above. If these same people were to meet some of these food needs by growing their own locally in home and community gardens, using for example, permaculture techniques, the carbon footprint would be reduced to approx 16 tonnes pa.

There are many benefits of moving beyond the individual building scale to a wider land development/community (eg urban village or precinct) scale when attempting to decarbonise. The main reason is that it allows a variety of other decisions, beyond the building fabric itself, to be taken into consideration when designing a development. These include decisions about transport as well as infrastructure options such as decentralized energy, water and waste. By including the emissions associated with these options, one can start to understand the carbon implications and benefits of these services, which are often taken for granted or seen as things beyond our immediate control.

Incorporating these factors into a design framework, such as *Envirodevelopment* by UDIA, allows developers to choose between various options that have differing carbon efficiencies, which can lower the footprint of the development and make the opportunity to become carbon neutral significantly easier. The key strategies deployed to ensure the 20% GHG emissions reduction target is achieved under *Envirodevelopment* are: reduced energy usage through design; demand management devices and programs; use of alternative energy sources; and use of more GHG efficient appliances and fixtures.

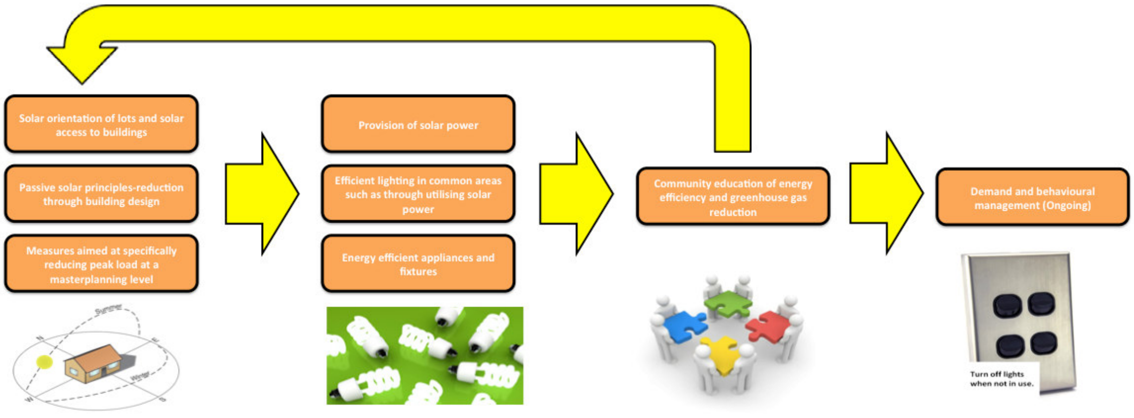


**Figure 1:** Urban Village Implementation Process for *Envirodevelopment* Energy Element

Urban developments awarded the *Envirodevelopment* Energy leaf include the following:

QLD; Brisbane City Council Bretts Wharf, Teneriffe and Hawthorne CityCat Ferry Terminals: **Each terminal has solar arrays** and, as in all BCC facilities, Brisbane City Council purchases 100% green power for additional energy used.

QLD; Eko:bode is a modern eight unit apartment building in the heart of Surfers Paradise. The property has a **6kW solar power system** and tenant support to adopt more efficient behaviours.

SA; Beyond Today by Environmentally Sustainable Developments (ESD), has 90 hectares with 220 residential lots at Victor Harbour. **All homes have at least 1kW RE system**, if air-conditioners are installed additional RE is required, and each home must have a solar hot water system.

SA; Blackwood Park is located approximately 15 km south of Adelaide CBD, the site has 168.7 ha and approximately 1200 residential allotments. Blackwood Park has achieved a 53% reduction in energy through solar passive design and **installation of photovoltaic cells**.

WA; Parkland Heights is located 40km south of Perth on 120 hectares with 1,200 lots. Initiatives to reduce energy consumption include maximum number of lots with ideal solar orientation; $4,000 “cash back” on **1.5kW rooftop solar photovoltaic systems**.

WA; The Evergreen Eco Village is an exclusive precinct within the greater Capricorn Yanchep development with 54 lots. Initiatives forecast to achieve 74% reduction in GHG emissions: solar hot water systems; **2.0kW photovoltaic systems installed in all dwellings**; solar passive design.

WA; Within the wider Alkimos project at the northern fringe of metropolitan Perth, the South Alkimos development by Landcorp and Lend Lease covers 224 hectares and will accommodate a population of approximately 6,000 in over 2,000 dwellings. New approaches will be used for local electrical network design and in home circuitry, metering and energy monitoring. Lend Lease have allowed for **2218 lots to receive a 1kW PV Array**.

Clearly, these developments are not achieving ‘carbon neutral’ status but they are often moving well beyond the 20% reduction target and demonstrating a way forward as well as an incentive for others to follow or exceed their example.

Learning from these experiences it is now understood that the supporting document necessary to claim the Energy 'leaf' under *Envirodevelopment* is effectively an Energy and Emissions Management Plan with the following strategies to enable the delivery of the above criteria:

1. Gain an overall understanding of expected energy use and investigate different scenarios of energy and emissions reduction.
2. Describe level of solar lot orientation and how this assists with GHG emissions reduction;
3. Alternative energy sources (eg rooftop photovoltaic power systems with preferred suppliers and designs identified). In particular, at least two models of PV system delivery exist;
4. Energy efficient appliances and fixtures (eg lighting and control systems with preferred suppliers and designs identified);
5. Energy efficient building design (this will include liaison with builders to identify affordable strategies to increase energy rating of homes greater than 6-star followed by thermal performance modelling to include energy savings in the energy mass balance below at 9);
6. Develop peak load management strategies and how these will be implemented with distributor (eg direct load control devices with Western Power) and householders (eg demand response enabling devices installed in air-conditioners and pool pumps);
7. Develop implementation strategy in consultation with electrical engineers & distributor;
8. Community education and behavioural strategies for energy management;
9. A quantitative energy and GHG emissions mass balance model to verify the 20% reduction target and enable ongoing monitoring and validation.
10. A monitoring and evaluation program that enables home-owner self-management through a Home Area Network (HAN) and a village-wide performance assessment every 12 months through a Local Area Network (LAN) for combined peak load management and PV strategy.

There are two models referred to above for alternative power sources. Firstly, a mass roll-out model under contract to a single provider with significant discounting and finance repayment plans devolved to all home-owners (this model would include 3kW for each house and be designed for complete energy self-sufficiency with grid connection only for peak demands while eliminating peak loads during normal operation). Secondly, an incentive package from the land developer that still achieves significant cost savings for home-owners through minimum purchase guarantees from several providers (this model allows installation of 1.5 to 5kW PV systems to a set to the required minimum number of homes necessary to achieve the 20% reduction target as well as satisfying peak load management requirements of the network manager Western Power).

The above planning method can enable new urban villages to go beyond the 20% GHG emissions reduction target and reach a 'zero energy development' but achieving a carbon neutral status would require additional measures that address the complete lifecycle of the development.

## Solar Energy for the Minesite Camp

Minesite camp stationery energy is typically provided by diesel or gas generation with diesel backup. This represents the operational energy. The remainder of the carbon emissions the camp is responsible for during its complete life cycle can be accounted for by transport, water supply, waste management, construction and not least the embodied energy of the built form and service infrastructure (Anda *et al*, 2011), plus demolition and site remediation. It is the complete offset of the total carbon emissions from all areas, the carbon footprint, that permits describing the camp as 'carbon neutral.'

Quantitative analysis required metering and monitoring of the camp power services. Remote data logging equipment was installed and commissioned in October, 2011 throughout the case study camp and data has been collected during the Australian summer season.

As with most mining camps in Australia, the camp is connected to the mine power station via a 22 KV transmission line. The power system under normal operation is 7MW, constituting five 1.22 MW Deutz gas generators and one 0.7MW diesel generator. The transmission line between the camp and the power system was close to 10 km. The distance between the mine generation plant and the camp is a significant factor. If construction of the connecting power line could be avoided, thus taking the camp of the mine grid, then a substantial saving could be put towards the RE system itself. The cost per kilometre of the poles and wires varies according to location and ground conditions between $50k and $200k, which in this case study would facilitate up to $2M towards the cost of the RE system(s).

The RE resources were identified and assessed. A Multi-Criteria Analysis (MCA) was used to determine the likely RE system, or combination of systems, appropriate to the camp. After undertaking the MCA, in order of suitability the options were: PV the best option; wind second; concentrated PV third; solar thermal fourth; and biomass last. A comprehensive resource assessment was then undertaken using regional assessment modelling tools to determine RE resource potential; data comparison and analysis of the various RE systems; and final selection of system or mix of systems. Solar PV followed by horizontal axis wind turbines were the only viable options in this case.

RE was assessed as retrofitted to the current power system and then in a standalone configuration. In both situations a variety of wind turbine and PV array sizes were investigated. At first it was decided to use HOMER to undertake this task. However, HOMER is designed essentially to model stand-alone systems and not RE systems connected to an alternative power system or grid as in the case study. An Excel spreadsheet to acquire the appropriate economic RE mix for the case study camp was developed and referred to as REMAX©. Furthermore HOMER is not designed to model two configurations of generation at the same time, one meeting 80% of demand (for example) and another 20% of the load. REMAX is based on the same principles as HOMER but can be modified to suit any load configuration. This study is only focused on the camp and does not include the mine operation.

The key dependencies in a net prime cost calculation that determine the viability of RE system inclusion the case study mine site are: connection to existing power generation system or not; size and selection of renewable system; the project life and start up date; and cost saving as a standalone system independent of the mine generation system. The cost of PV, according to market sources, will continue to drop as will the cost of wind generation and the viability of RE systems improves in time according to installation date.

**Figure 2**: NPC analysis for project starting in January 2013 and 2018 with variable project life

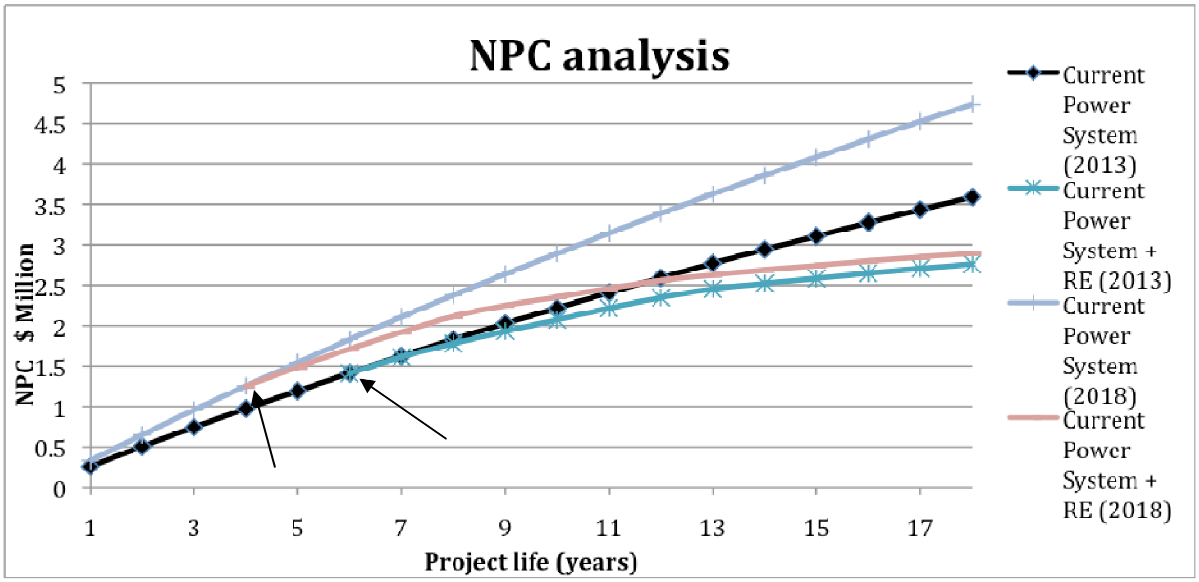
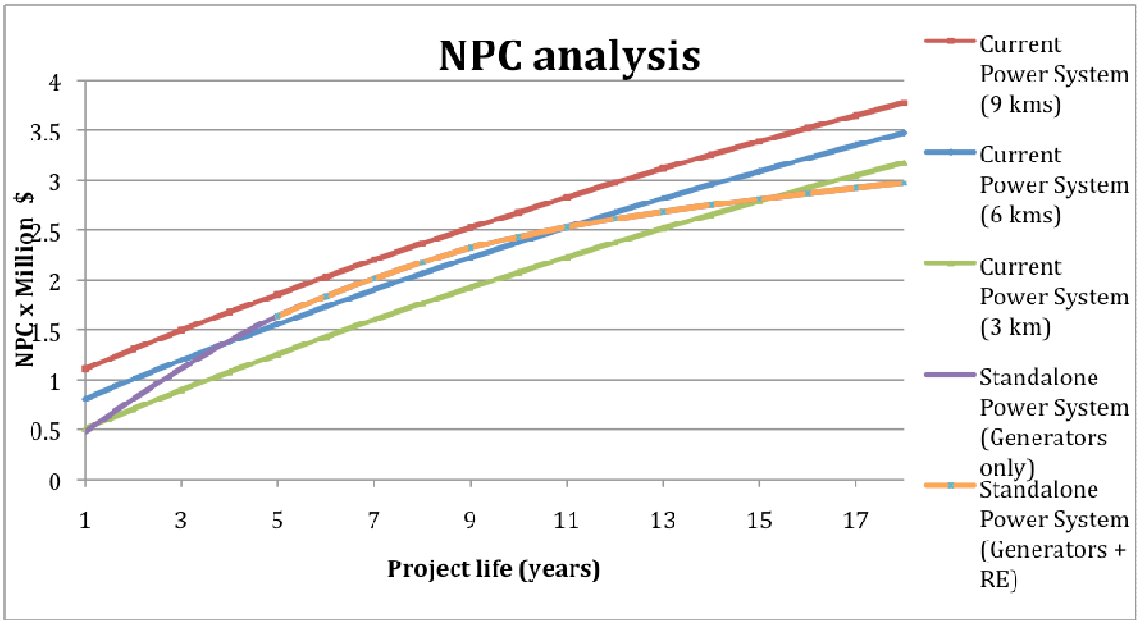


**Figure 2** above illustrates that RE becomes cost positive, with a discount rate of 8%, between 4 and 6 years (depending on installation date) whilst connected to the existing mine generation system. As

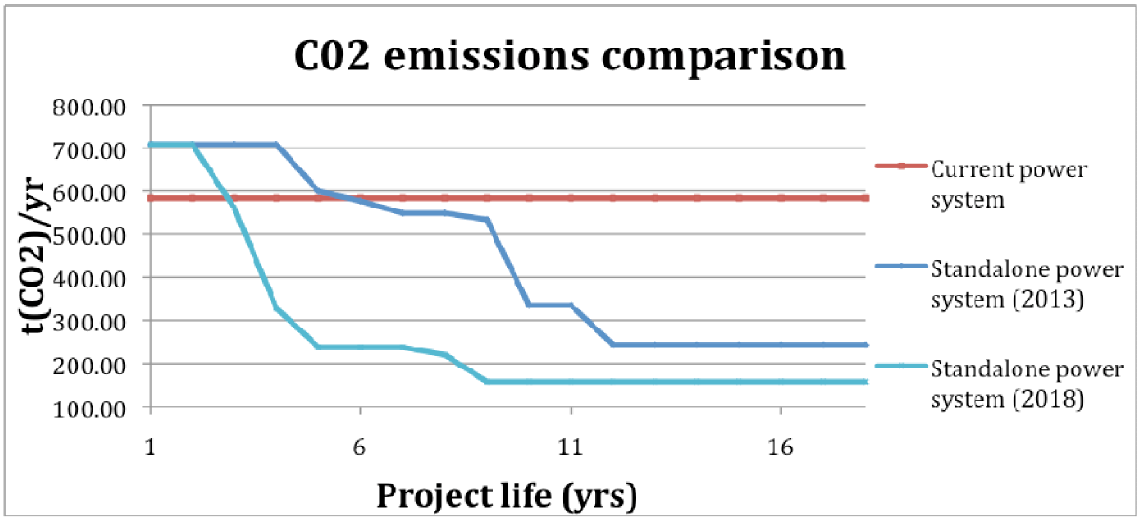
mentioned earlier if the supply connection between mine generation plant and camp is removed, making the RE system stand alone, then the significance of the capital cost saving improves the viability of RE as shown in **Figure 3** below where connections to mine site plant are plotted at distances of 3, 6 and 9 km. However, analysis shows that where the distance is 3km or less RE only becomes cost positive if the project life is 15 years or greater. This is assuming a transmission line cost of $100,000/km and a discount rate of 8%, both of which are conservative.

**Figure 3:** NPC comparison for different project lives (Transmission line cost: $100,000 per km).



In the current case study introduction of a standalone RE system(s) did not automatically reduce emissions below that of the existing power generation, as illustrated in **Figure 4** below. The reason for this is that the RE system required low-cycle diesel generators as backup and diesel is far more carbon intensive than the current gas powered generation. The cost of RE is projected to reduce in time permitting purchase of a larger system for the same cost with an equivalent reduction in carbon emissions as a result between 2013 and 2018.

**Figure 4**: $CO_2$ emissions comparison for a project starting in January 2013 and 2018



## Solar Energy for the Remote Indigenous Settlement

Indigenous communities are dispersed across the remote areas of Australia where in the past it has been difficult to deliver electricity. In the late 1900s, diesel generators became cheaper and were often installed in communities sometimes even replacing existing windmills (Lloyd et al., 2000). The high levels of solar radiation across these regions and the increasing energy efficiency and cost effectiveness of solar photovoltaic technology systems are now making it increasingly desirable to provide solar power.

According to the latest ABS survey of Indigenous Housing and Infrastructure in 2006 (Australian Bureau of Statistics, 2007) only 212 (18%) of the 1187 communities in Australia had solar or solar hybrid as their main power supply source. Another 555 (47%) were reliant on community or domestic generators and 32 (3%) had no electricity supply. The remainder where supplied by grid or unspecified supply systems.

Since 2006 further systems have been installed. From 2001 to 2009 the Federal Government funded the Renewable Remote Power Generation Program (RRPGP), which included installation of solar PV systems in Indigenous communities. Many of these were installed by the non-government organisation Centre for Appropriate Technology (CAT) via their Bushlight program. The program was begun in 2002 in response to audit findings that renewable system installations had been inadequate (Lloyd et al., 2000). Since then they have installed over 140 systems.

The federal government is also planning increased roll-out of solar technology through the $40 million four-year Remote Indigenous Energy Program (RIEP) (FaHCSIA, 2012), which is part of the Clean Energy Future package. The program's aim will be to supply 50 small (population less than 50) remote communities with reliable 24-hour power supply. Many of those supplied are likely to be solar or solar-hybrid systems.

The Northern Territory Government also recently announced its commitment to replace diesel as a primary source of power generation in remote towns and communities (Green Energy Taskforce, 2011). In 2009 over 31 million litres of diesel was used to power the major remote communities in the Territory, equating to over 90,000 tonnes of CO2-e. The two components to their plan are: 1) To integrate 10MW of PV into 46 diesel power stations. These are expected to provide a 17% reduction in diesel use without the need for expensive modifications or installation of storage systems at a cost of $60 million; and 2) To define options for total replacement of diesel use with renewable technologies and low-emission fuels.

The Federal department for FaHCSIA were able to provide an overview of diesel use by community population size for the financial years of 2008/09 and 2009/10 (FaHCSIA, 2011). From their records they randomly sampled five communities within each size category and reported the sum of the population and litres of diesel use in each category. This was averaged and the results in **Table 2** reveal the estimates.

**Table 2:** Overview of diesel use for financial years f 2008/09 and 2009/10 (FaHCSIA, 2011).

| Community population | Average sample population | 2008/09 litres | 2009/10 litres | Average litres | Average litres per capita |
|---|---|---|---|---|---|
| Small <100 | 61 | 126,528 | 128,060 | 127,294 | 2,080 |
| Medium 100-199 | 132 | 286,831 | 272,908 | 279,870 | 2,117 |
| Large 200+ | 416 | 630,978 | 631,594 | 631,286 | 1,516 |

While at first the results may seem to indicate a significant economy of scale, this is partially due to the inefficiency of small diesel generators and a more thorough analysis is required. For example in

2004, Bushlight commissioned two household PV arrays in the small community of Wulununjur (Bushlight, 2004). The community had previously been using $12,000 worth of diesel per annum. The arrays provided a combined capacity of 5.1 kWp PV array with a maximum daily AC load of 11.1 kWh and DC load of 1.4 kWh. Other energy needs were provided by gas for cooking indoors, firewood for cooking outdoors and water heating and further solar power for water pumping. Diesel was only expected to be used occasionally when high-powered appliances were used or a significant number of visitors stayed during times when ceiling fans were required. The load of approximately 6 kWh per household is significantly lower than the average household and the switch to solar energy greatly reduced their carbon footprint.

Critical to the scale of the supply system is the energy efficiency of the housing and other buildings in the community. Estimates of average Australian households in 2008 reveal that cooling and heating require 38% of their energy demand (Reardon et al., 2010). This is likely to be similar or higher in remote communities, for those with air-conditioning, as their housing is often inappropriately designed for temperature control and the history of chronic underfunding results in a poor standard of maintenance (Fien et al., 2008). Therefore addressing the energy efficiency of the housing and its climate-responsiveness, either through retrofitting or new housing, is essential to designing an achievable demand load and electricity costs that are within a low-income household budget.

Making informed choices about energy use is also essential to the effective use of the supply systems. Bushlight provides energy education programs to its RE program residents and designs an energy budget for each household prior to installation. An energy-monitoring unit (EMU) is also installed which facilitates effective management of the power supply (Centre for Appropriate Technology, 2010a; Centre for Appropriate Technology, 2010b). Energy education programs have also been conducted in Queensland communities with Ergon Energy (Centre for Appropriate Technology, 2010a) and in the Northern Territory. Horizon Power has run a similar pilot program in some WA communities, which includes energy education and some retrofitting to enhance energy efficiency of housing (Horizon Power, 2010).

## 8. Conclusions

The results of data collection and analysis above enabled carbon reduction plans to be formulated for the three settlement types. These are summarised in Table 3 with examples of key strategies given.

**Table 3:** Outline of Carbon Reduction Plan for each Settlement Type.

| **Element** | **Urban Village** | **Minesite Camp** | **Indigenous Settlement** | **Cumulative emission reduction** |
|---|---|---|---|---|
| Understand energy & GHG | Energy & Emissions Management Plan | Level 2 energy audit AS3598 | Community Development Plan | |
| Behaviour change | Living Smart program | Staff induction program | Sustainable Livelihoods Framework | 10% |
| Energy efficiency | Land purchase incentive packages | Accommodation module upgrade | Fixing Houses for Better Health program | 20% |
| Monitoring & control | HAN, LAN with IHDs & DLC via smart grid | DLC via mine HQ & control centre | DLC network from community office | 30% |
| Renewable energy | Rooftop PV, district geothermal for HVAC | Rooftop PV & solar/biomass stn | Rooftop PV and solar farm | 80% |
| Offsets | Biophillia, peri-urban RE power stations | Biosequestration | Biosequestration | 100% |

The key strategies for urban villages are: solar orientation of lots and solar access to buildings; measures aimed at specifically reducing peak load at a masterplanning level; efficient lighting in common areas such as through utilising solar power; community education of energy efficiency and greenhouse gas reduction; provision of solar power; energy efficient appliances and fixtures; passive solar principles – reduction through building design; and demand and behavioural management.

Monitoring and data collection systems were installed in a minesite camp and the data used in a new modelling tool to evaluate different renewable energy systems to offset total lifecycle emissions. These systems were found to reduce emissions below that of the existing gas-fired power generation somewhere between 2013 and 2018 and carbon neutrality achieved through biosequestration for the balance of lifecycle emissions. In the case of remote indigenous settlements opportunities for sustainable livelihoods linked to renewable energy in the new carbon economy include energy efficient home construction, solar power installation and participatory community education programs.

## Acknowledgement

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