# OVERCOMING TECHNICAL KNOWLEDGE BARRIERS TO COMMUNITY ENERGY PROJECTS IN AUSTRALIA

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# ABSTRACT

Community energy projects have the potential to increase the sustainability of Australia's energy sector. The purpose of this research is to create an enabling tool to help community energy proponents overcome technical knowledge constraints. In this thesis, technical knowledge is understood to encompass the wider environmental and economic issues associated with specific energy technologies and community energy projects are defined as having the following three features:

- Use of renewable energy or low carbon technologies,
- Distributing/localising supply; and
- Democratising governance through community ownership and/or participation.

A barrier-benefit analysis of community energy projects identified that lack of technical knowledge in communities as a key barrier. To help overcome this barrier the Community Energy Decision Assistance Tool (CEDAT) was developed based on a review of: existing energy tools available to communities; sustainability decision making frameworks; a user analysis; and appropriate technologies. CEDAT uses an MS Excel platform to provide users with a multi-criteria decision analysis process for five community scale, low carbon energy technologies (wind, mini-wind, solar photovoltaics, agricultural biomass and cogeneration), based on community specific input data. The aim of CEDAT is to provide a framework for users to better understand low carbon technology options suitable for a specific community.

To evaluate the usefulness of CEDAT it was applied to a case study – the Sydney Coastal Ecovillage Project (SCEV). SCEV is a project in the early planning phase, which aims to create an environmentally and socially sustainable village for approximately 300 people on the Central Coast of NSW. The results of the application of CEDAT to SCEV indicate that mini-wind would be the most viable energy option and should be the target of further investigation.

CEDAT has the potential to assist communities in the initial stages of developing a community energy project, specifically by providing an easy to use framework for discussion, with technical, environmental and economic outputs that can become the basis for further investigation. It is limited due to the number of technologies and the simplicity of the energy modelling, which could be addressed with further development.

# ACKNOWLEDGEMENTS

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**ORIGINALITY STATEMENT**

'I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.'

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# 1. INTRODUCTION

## 1.1. STATEMENT OF TOPIC

This research project considers the barriers to the development of community energy projects in Australia. It is informed by the international context of climate change, and the Australian socio-political context.

Global climate change is arguably the biggest challenge facing contemporary society. The likely impacts range from the loss of the Great Barrier Reef due to coral bleaching, to the creation of over 150 million climate refugees (Myers 1993). Recent scientific research suggests that climate change is happening even faster than anticipated. The scale and the urgency of the problem are unprecedented.

While Australia is likely to be the industrialised country hit hardest by climate change (Garnaut, 2008), we are also one of the highest per capita greenhouse emitters in the world, largely due to our dependence on coal generated electricity. Climate change is a 'wicked problem' (Rayner 2006), to have any hope of averting the more severe impacts will require significant societal transformation. As such, community based actors are likely to play an important role in enabling this transformation. In 2005-06, Australia saw a tipping point; the consciousness relating to climate change saw the rise of over 100 community climate groups, across Australia (Diesendorf, 2008). These community groups are ordinary people motivated to action based on a common concern about climate change. The actions undertaken by these groups range from awareness raising, to political advocacy, to developing practical initiatives to reduce their community's footprint.

In Australia, stationary energy contributes 50% of Australia's greenhouse emissions (DCC, 2008); while centralized coal fired power stations generate 80-85% of Australia's electricity. Given the reality of climate change, it is clear that a transition to a more sustainable technology regime is necessary. Kemp et al (1998 in Walker et al, 2006) suggest that "the task is no longer to control or promote a single technology but to change an integrated system of technologies and social practices." Increasingly, there is a perception within the community that governments have and are continuing to fail to initiate this transition to a more environmentally sustainable energy sector. In response, communities are investigating ways to generate their own low carbon energy.

Internationally, energy co-operatives and community energy projects, initiated by community groups similar to Australian community climate groups have been important in democratising, decentralising and decarbonising energy systems, particularly in industrialised countries. For example, wind power supplies almost 20% of Denmark's energy, of which 80% of the turbines are owned by households and communities (CREA, 2006). Another example is the UK town of Woking, which has undertaken a series of

energy efficiency programs and started an Energy Service Company (ESCo), which has reduced emissions community wide by 21% (Thompson, 2007). Additionally, Woking Council's electricity infrastructure is 99.85% self sufficient.
Despite the power of these community energy projects, they face significant barriers to development particularly in Australia.

The motivation for this thesis is to create a tool that helps Australian community groups to develop sophisticated, community based, low carbon energy projects. The problem that this research aims to address is the technical knowledge barriers that community energy project proponents face.

## 1.2. SCOPE

This research aims to:

- Identify a range of barriers to the implementation of community energy projects, including technical, economic, environmental, social and political barriers
- Identify tools that have been developed elsewhere to overcome these barriers;
- Identify and review the most promising commercially available technologies appropriate for community energy projects in Australia;
- Create a new tool – the Community Energy Decision Assistance Tool (CEDAT) that community groups can use to overcome technical knowledge barriers to implementing community energy projects;
- Trial this tool by working with members of the Sydney Coastal Ecovillage to investigate energy technologies appropriate for their community energy project.

This research will *not*:

- Look in detail at the interactions between the institutional and technical arrangements of community energy projects;
- Analyse the current energy policy setting in Australia;
- Review and incorporate all possible energy technologies into CEDAT;
- Consider demand side response to energy including energy efficiency; or
- Undertake a sensitivity analysis of the results generated by applying CEDAT to the case study of Sydney Coastal Ecovillage.

## 1.3. OVERVIEW OF REPORT

This report is structured as follows:

Chapter 1 provides an outline of the thesis topic and overarching background and context, details the scope of the project and identifies the aims of the research

Chapter 2 gives an overview of the community energy literature, specifically defining the term community energy project

Chapter 3 provides a brief introduction to the Australian energy sector, to further contextualise community energy.

Chapter 4 reviews the barriers to and benefits of community energy projects using a STEEP (social, technical, environmental, economic and political) framework. Existing resources and which barriers they target are then explored with the aim of identifying the gap this research can fill.

Chapter 5 explores methodological approaches that could be the basis for addressing the issue of technical knowledge constraints facing community energy projects. Specifically two energy models and multi-criteria decision analysis processes are discussed.

Chapter 6 identifies the important features associated with an energy technology suitable for use in a community energy projects and then reviews four such technologies for the purpose of determining which could be incorporated into a community energy decision assistance tool.

Chapter 7 outlines and discusses the modelling processes involved in CEDAT, including refining its purpose, inputs and outputs.

Chapter 8 outlines the application of CEDAT to the case study of the Sydney Coastal Ecovillage, including detailing the research process undertaken and the inputs and results determined through a trial of CEDAT.

Chapter 9 discusses the results of the case study and evaluates the general usefulness of CEDAT in overcoming technical knowledge constraints to community energy projects in Australia, as well as presenting recommendations for improving CEDAT and identifying new potential areas for research.

## 2. COMMUNITY ENERGY PROJECTS

Internationally community energy projects have their roots in the normative activist discourses of the '60s and '70s (Dunn, 1978; Lovins, 1977 in Walker and Cass, 2007), neo-communitarian discourses of local participation and empowerment (Vertical Project, 2001 and Walker et al, 2007 in Walker and Cass, 2007) and discourses of environmental sustainability (Vertical Project, 2001). Despite or perhaps because of their increasing abundance, the definition of community energy projects is contested. Walker et al's (2007) review of 12 UK community energy initiatives found many more than 12 different understandings of the term community energy. These understandings fell broadly into four categories:

- Legal – specifying the legal entity or institutional arrangement of the project as being without commercial interests
- Physical – involving community buildings or spaces
- Process – involving local people
- Financial – local people having a financial stake in the project (Walker and Cass, 2007).

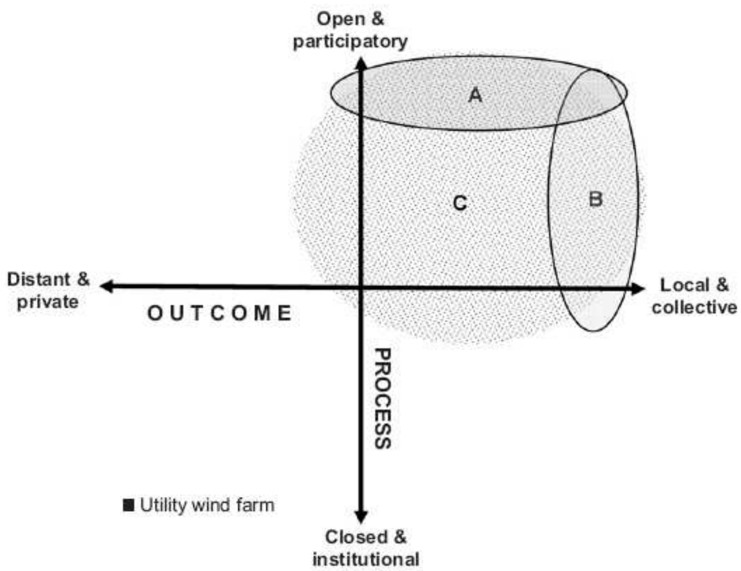



**Figure 1: Understanding of community renewable energy in relation to project process and outcome dimensions (Walker and Cass, 2007)**

Walker and Devine-Wright (2008) further distil these categories into two key dimensions that underpin community energy – process and outcome (depicted in Figure 1). The *process* dimension is concerned with who a project is developed and run *by* while the *outcome* dimension is concerned with how the outcomes of a project are spatially and socially distributed – who is it *for* (Walker and Devine-Wright, 2008, emphasis in text). From Figure 1 it is clear that there are multiple possible social or institutional arrangements associated with community energy projects. Four of the key institutional forms that community energy projects take are:

- Energy co-operatives. Energy co-operatives are projects, often wind farms where "people in the local community or further afield become members of the cooperative and buy shares to finance the project" (Walker 2008). Examples of energy co-operatives include Middelgrunden in Denmark, Baywind in the UK and the proposed Hepburn Community Wind Farm in Victoria.

- Community charities or not-for-profit organisations. These usually take the form of an association with charitable status that provides or runs facilities for the local community which utilizes a community energy project. They can also have trading arms which provide energy services or programs (Walker 2008). Examples include the Moreland Energy Foundation in Melbourne.

- Shares owned by a local community organization. This is where a developer of a commercial energy project gifts shares in the project to a community organisation (Walker 2008), to provide ongoing benefit and revenue to the community as well as some degree of control. Examples include the Earlsburn wind farm in Scotland.

- Energy Service Companies (ESCos). These are companies, often set up by local councils (for example Thames Ltd which was set up by Woking Borough Council in the UK) are a vehicle through which energy and environmental services such as heating and lighting and emission reductions can be delivered. They can have a flexible corporate structure examples include limited company or social enterprise (Thompson, 2007). Another example is the Australian company Grid X.

These are different legal or financial models of community energy projects; they correspond to different degrees of community ownership, participation and control and are more or less appropriate to different technologies. Walker and Cass (2007) also distinguish community energy from public utility, private supplier, household and business models of energy projects. However, this list does not include municipal energy projects, such as ESCos, which area hybrid of community, business and private supplier models of energy. Holmes A'Courte (2009) furthers the distinction of community energy projects from other models by emphasising that there are five orders of magnitude between the scale of technologies promoted in current Australian energy policy – household and centralised scale energy. Centralised energy projects are large scale or macro technologies in the 100s of megawatts range. They require significant upfront capital and are therefore usually undertaken by publicly owned utilities or large corporations. Household energy projects are those projects that a single person or household could undertake for themselves, for example installing solar panels or solar hot water systems on a household roof, they are micro technologies in the ~1kW range. The gap between utility and household scale energy projects 10s kW-10s MW (micro-meso technologies), is the range in which community energy projects are best suited (Holmes A'Courte, 2009; Walker and Cass, 2007).

Technically as well as institutionally, there are many configurations available to community energy projects. Holmes A'Courte (2009) suggests that energy co-operative arrangements for community energy projects are technology neutral, while Walker and Cass (2007) list a number of appropriate technologies which are discussed in detail in Section 6.

For the purpose of this research, community energy projects will be defined as having the following three features:

1. Use of renewable energy or low carbon technologies - decarbonizes,
2. Distributing/ localising supply; and
3. Democratising governance through community ownership and/or participation.

## 3. AUSTRALIA'S STATIONARY ENERGY CONTEXT

To better understand the potential and importance of community energy projects and where they fit in the Australian Energy System a brief overview of Australia's stationary energy context is provided. This overview, mainly focuses on the electricity system, including generation, distribution and use.

The Australian electricity supply sector has an installed grid-connected generating capacity of 47,400 MW and a further 4200 MW in embedded and non-grid generating capacity (ESAA 2008). The supply sector is connected to end-users by 884,000 circuit kilometres of electricity transmission and distribution networks.

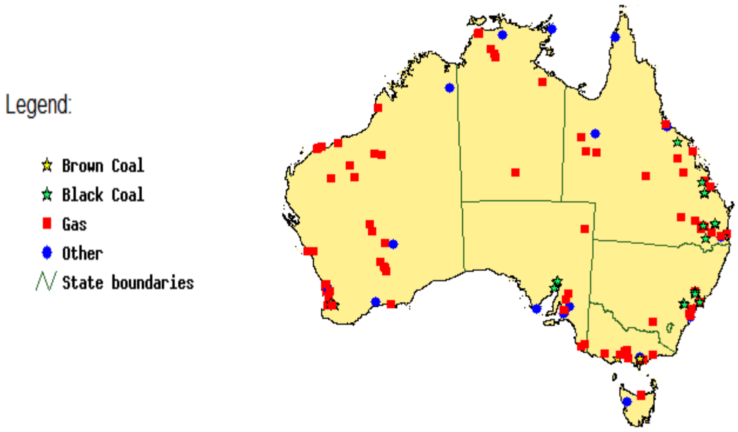



**Figure 2: Fossil fuel generators in Australia (Geoscience Australia, 2009)**

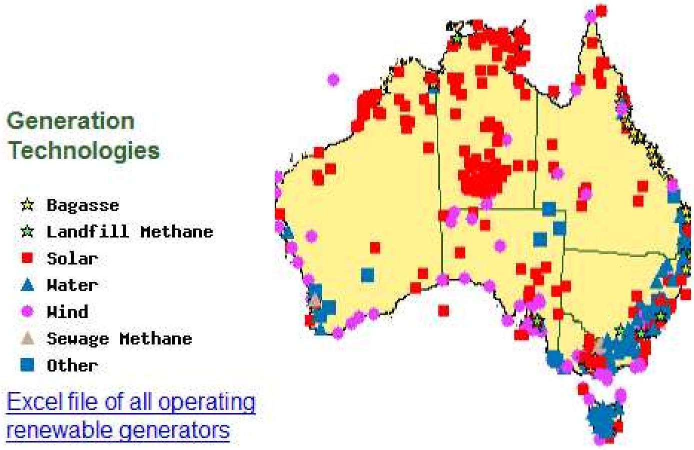



**Figure 3: Renewable energy generators in Australia (Geoscience Australia, 2009)**

In 2006-07 the electricity supply sector generated 226,600 GWh of electricity, this comprised 56.7 per cent from black coal, 24.5 per cent from brown coal, 12.2 per cent from natural gas, 6.1 per cent from hydro, and 0.6 per cent from oil and other fuels (ibid). The electricity was consumed by the following sectors of Australian society in the following proportions:

- Residential – 27.8%
- Commercial – 22.4 %
- Metals – 18.1 %
- Aluminium smelting – 11.6 %
- Manufacturing – 9.2 %
- Mining – 9.1 %
- Transport and storage – 1.0 %
- Agriculture – 0.8 %

Figure 2 shows the distribution of fossil fuel generation technologies across Australia, while Figure 3 shows the distribution of renewable generation technologies larger than 3kW.  As such, while there is clearly more individual renewable energy powered generators than fossil fuel powered generators, this is because renewables are smaller scale, distributed technologies.  The generation statistics from ESAA (2008) clearly indicate that the majority of Australia's electricity is generated by coal (81%), which is the most greenhouse emissions intensive fuel.   Greenhouse gas emissions from electricity in Australia totalled 194 mtCO2-e in the 2005 inventory year (ibid), which accounted for 50% of the nation's domestic emissions.

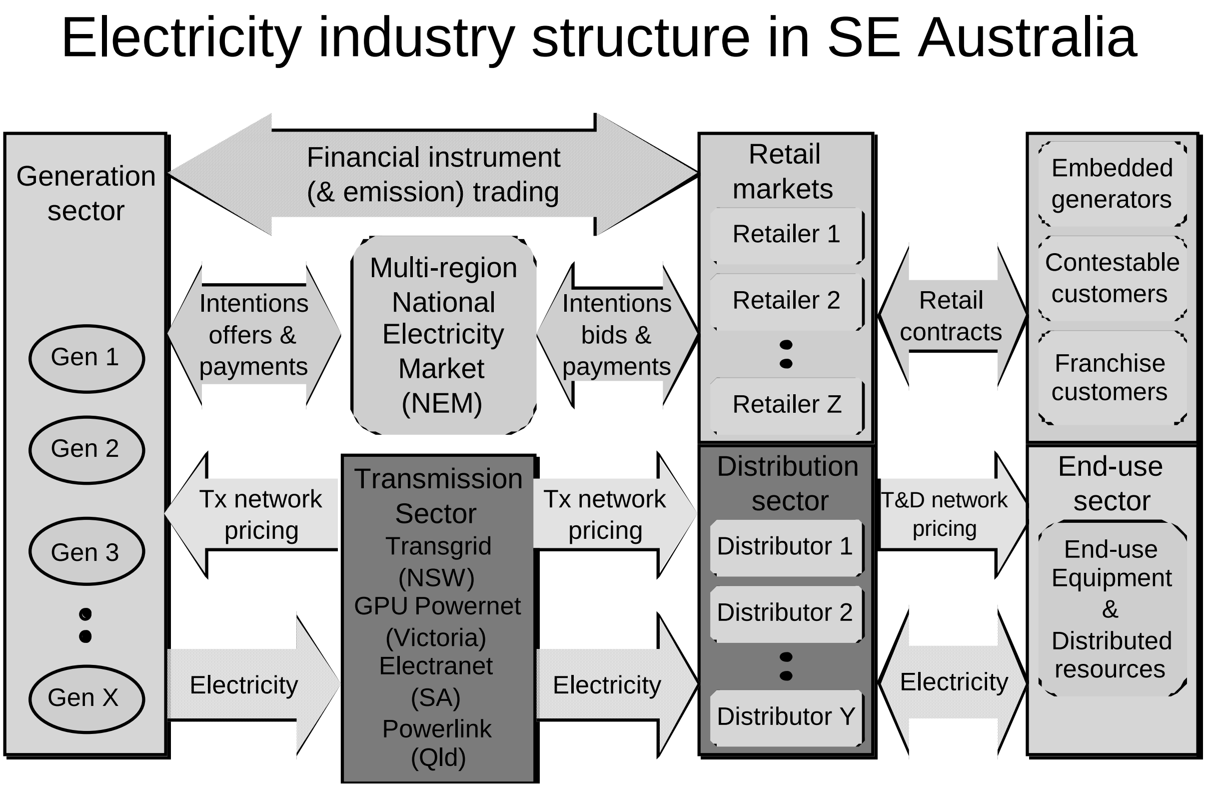



**Figure 4: The restructured electricity industry in Australia (Outhred, 2000)**

The Australian electricity industry in addition to the generators comprises of a different sectors which are mapped in Figure 4.  Figure 4 is a model of the restructured electricity industry in South-East Australia, which is an interconnected, multi-state power system that extends over 4000km (Outhred and MacGill, 2006).  Restructuring of the Australian electricity industry "formally commenced in 1991 under an agreement reached by the Council of Australian [Federal and State] Governments (COAG)" (ibid); the process led to an industry with the following features (ibid; Outhred, 2000):

- A disaggregated (NSW and Queensland), long-term leased (South Australia) or privatised (Victoria) supply sector, which was formerly in the form of a state-owned monopoly;
- A formal entity called the National Electricity Market (NEM), with new policy frameworks and regulatory regimes;
- Wholesale spot energy and ancillary markets where electricity is traded every 5 minutes based on 30-minute average spot prices;
- A single spot market and system operator for the whole of the NEM, initially called the National Electricity Market Management Company (NEMMCO) and now known as Australian Energy Market Operator (AEMO); and
- A retail market which has partially or completely elimination retail franchises, such that most end-users are now contestable consumers.

The legislation guiding the electricity industry focuses primarily on the wholesale energy market, almost completely ignoring end-users (Outhred, 2000). As such, the supply sector, which is dominated by large generators, is the major focus of the Australian electricity sector. This represents significant barriers to energy efficiency and demand side policies and projects and the establishment of an energy services sector, which sit on the right-hand side of Figure 4. Internationally an energy services approach to the energy industry has proven to be a more environmentally efficient approach to energy.

Currently, much of the work being done to address barriers to energy services are top-down policy or industry approaches. For example, AEPCA (2005, in Outhred and MacGill, 2006) "argues that five policy elements will be required for ESCOs to achieve their potential – broad-based market signals for energy efficiency investment, making energy markets work on the demand-side, minimum performance regulations for the built environment, driving greater energy efficiency in manufacturing and developing the emerging energy services industry". Community energy, which can be considered one approach to energy services, represents a bottom up approach which is arguably missing from the literature. The power of community energy projects, situated as they are in a local context means that:

- It is theoretically possible to closely match supply and demand loads;
- End users can be empowered and enabled to be active agents in the electricity market; and
- Greenhouse emissions associated with energy particularly those generated to supply residential and commercial sectors (50.2% of total electricity emissions) can be reduced.

The first two benefits of community energy according to Outhred (2000) and Outhred and MacGill (2006) are missing from the existing energy market.

# 4. COMMUNITY ENERGY BARRIERS, BENEFITS AND EXISTING RESOURCES

To determine the knowledge boundaries that this research can expand, a review of the benefits of, barriers to and existing resources available for community energy projects has been undertaken. In addition to reviewing the literature, leading Australian community energy proponents were consulted for their opinions on the barriers and benefits facing community energy projects. Those consulted included:

- David Shapero – Managing Director, Future Energy
- Brad Shone – Energy Strategy Manager, Moreland Energy Foundation
- Philippa Rowland – Clean Energy for Eternity
- Ian Lett – Central West Renewable Energy Group
- Simon Holmes A'Courte – Chairman, Hepburn Wind

A STEEP framework was applied to structure this review process. STEEP is a knowledge management or assessment framework which stands for Social, Technical, Economic, Environmental and Political/Policy. The STEEP framework builds on a triple bottom line assessment, as it considers not only environmental, economic and social factors, but also technical and policy or political factors. As an assessment tool, STEEP is reasonably comprehensive, without becoming too complex, it enables a holistic look at a topic, and in this case is used to categorize benefits and barriers to implementation.

## 4.1. BENEFITS & BARRIERS

For community energy advocates, the three defining features of community energy projects – use of low carbon technologies, decentralization of supply and democratization of governance are intrinsic "goods" or benefits which large-scale and individual energy projects arguably cannot possess. The literature describes a number of additional benefits which stem from the three defining features as well as the barriers community energy projects face. Community energy projects are not easy to initiate and develop, they are complex enterprises and have many stakeholders and processes to implement, whichever model or technology utilised.

### 4.1.1. TECHNICAL BENEFITS & BARRIERS

The technical benefits outlined for community energy projects include a more contextual, responsive and potentially innovative energy system (Hoffman and High-Pippert, 2005 in Walker; 2008, Vertical Project, 2001; Canadian Renewable Energy Alliance, 2006; Greenpeace, 2005). Specifically community energy projects can:

- Reduce the amount of wasted energy, by using more efficient technologies and reducing transmission losses (Thompson, 2008; Diesendorf, 2007; Greenpeace, 2005; Hepburn Wind, 2009);
- Increase reliability of electricity supply or energy service provision to rural and regional communities (Outhred, 2000; Cronan, 2000);
- Stimulate activity in the household sector to increase energy efficiency and thus potentially reducing peak load (Walker and Devine-Wright, 2008);
- Provides a platform for technological experimentation and innovation (Hepburn Wind, 2009); and
- Reduce load management issues, associated with large-scale renewables and increase voltage stability of the network (Walker, 2008; Hepburn Wind, 2009).

One of the most powerful technical benefits is the potential to match energy supply and demand profiles for a community (Thompson, 2008). However, this is a complex process, which requires skills and resources to manage, which communities may not have. Complexity of technology and the broader socio-technical system is thus a significant barrier to the development of effective community energy projects.

There is little information in the community energy project literature regarding technical barriers. This may be because the much of the literature is targeted at lay people, policy makers or geographers/social scientists. However, Greenpeace (2005) states that the major barriers to decentralised energy are political not technical. Although, there are barriers related to each specific technology, which are detailed in the technical review (Section 6). While a potential benefit of community energy projects is that they can ensure that the most appropriate technology for the community is chosen, there are knowledge barriers to this happening. Communities often lack the necessary technical and organizational capacity and knowledge to complete a community energy project. Specifically, a lack of technical knowledge can manifest as not knowing what sustainable energy technology are available or which are most appropriate for an area (Lett, 2009). For example, Clean Energy for Eternity in Bega, NSW had initially planned to develop a community owned solar thermal power project. However after an initial project scoping funded by a government grant, they determined that solar thermal was not viable so close to the coast, and thus changed to pursue a community owned solar PV power project (Rowland, 2009). The example demonstrates that communities need expert advice and support particularly in developing the technical viability of the project (Walker, 2008, CREA; 2006; DTI, 200?).

Also according to CREA (2006) there are few education and training courses in the operation and maintenance of renewable energy technologies and their deployment. They argue that a rise in renewable energy generally and community energy projects specifically will be impacted by a shortage in skilled workers. Although this is a report into the Canadian context, this barrier holds true for Australia as well.

### 4.1.2. ECONOMIC BENEFITS & BARRIERS

Economic benefits of community energy projects include:

- Creating new jobs, by undertaking and managing the project at a community scale (Walker, 2008; Hepburn Wind, 2009; Shone, 2009)
- Economic development within rural and regional areas (Jordan, 2000; Walker et al, 2006), specifically through the sale of generated energy being reinvested in the community, while also delivering a financial return to local investors;
- A reduction in the need for state governments, and transmission and distribution network operators to invest in upgrades to costly new infrastructure such as transmission lines and new centralized power stations (Thompson, 2008, Greenpeace, 2005; Rutovitz and Dunstan, 2009).
- Leveraging a new funding source – the community investor (Hepburn Wind, 2009)
- Saving money on grid connection either through:
    - Connecting to the electricity distribution network, thus saving the costs associated with larger renewable energy developments of connecting to the transmission network (Vertical Limit, 2001; Hepburn Wind, 2009); or
    - Bypassing the grid altogether, saving money and the complexity of dealing with network operators (Thompson, 2008); an example is the Woking heat and power network.

Despite these benefits, economic barriers are the most widely referenced in the literature. The overarching barrier given is the lack of access to financing for projects, although there is also reference to the broader discourse of economic rationalism pervasive within society as a barrier, particularly in the current "credit crunch" (Holmes A'Courte, 2009; Hepburn Wind, 2009). Financing is needed:

- For the initial development stages of community energy projects (CREA, 2006), where costs include undertaking the feasibility study and any time that expert advice is required (Schapiro, 2009, pers comms). These funds are difficult to secure as there is significant risk because there is not a guaranteed project at this stage;
- To cover capital costs, which are large, usually in the tune of millions of dollars;
- To cover the long term costs of keeping systems maintained, which may become significant and problematic unless an adequate income stream is being generated (Walker, 2008).

In addition to the reasons given above, there are a number of other barriers to community groups accessing the necessary financing. Firstly, with the exception of wind which is proven to be commercially viable, other renewable technologies have higher investment risks and longer return periods, making them harder to implement economically. Secondly, even for community scale wind energy projects, without a dedicated government funding program, it is difficult for community groups to organise a large enough share offer or bank loan (Walker, 2008, CREA, 2006). One of the reasons for this is that community groups lack a track record in the sector and financing institutions are unwilling or unable to take the risk (Hepburn Wind, 2009).

#### 4.1.3. ENVIRONMENTAL BENEFITS & BARRIERS

The most common benefit sited in the literature is a reduction of the environmental footprint of communities. No environmental barriers to community energy projects are identified, although there are barriers associated with specific technologies as discussed in Section 6. Other environmental benefits of community energy projects detailed include:

- An increase in environmental consciousness of communities;
- Reduced amount of water required for energy service provision, for example, "Victoria's coal based power generation in the Latrobe Valley consumes up to 20% of Melbourne's water supply every year" (ABS, 2005 in Thompson, 2008).
- Reduced smog and other air pollutants (CREA, 2006).
- More sensitivity to regional conditions and specific environmental context, as the planning and development processes utilize more local knowledge, than processes undertaken by organizations external to the community (CREA, 2006)
- Contributing to cutting greenhouse emission thereby reducing the community's contribution to climate change. Community energy projects do this by:
    - Reducing reliance on coal powered electricity and increasing the amount of renewable energy generation (Greenpeace, 2005, Thompson, 2008)
    - Reducing energy consumption of the community and changing the way society view and use energy (Greenpeace, 2005)
- Less severe impacts on wildlife; fewer negative hydrological effects; less erosion, less noise and less shadow flicker than centralized energy options (CREA, 2006).

#### 4.1.4. SOCIAL BENEFITS & BARRIERS

A review of the literature suggests that the social benefits of community energy projects include:

- Individuals and communities gaining a sense of satisfaction (DTI, 2000) and a feeling of contributing to tackling climate change (CREA, 2006).
- Increased likelihood of community support for the project, than if it were undertaken by a non-community based actor, as the power of example is unlocked (Hepburn Wind, 2009). This is significant as community opposition due to aesthetic

issues is probably the largest barrier to wind power in the world (CREA, 2008, Gipe, 2009).

- Increase equity of energy supply (Vertical project, 2001).
- Local control, ensuring the scale of development, site, orientation, financial benefits are managed so as to maximise community benefit (Walker, 2008).
- Increased community capacity and potentially cohesion (CREA, 2006; Walker et al, 2006) if associated benefits are shared amount local people (Walker and Devine-Wright, 2008).

These last three benefits reflect the widely emphasised points that community energy can revitalize local communities and economies and increase self-sufficiency, local determination and empowerment (Hoffman and High-Pippert, 2005 in Walker, 2008, Vertical Project, 2001, Canadian Renewable Energy Alliance, 2006 and Greenpeace, 2005). These benefits are as a result of communities participating in both the process and outcome of projects as discussed in Section 2. In encouraging individuals to participate in energy projects, the discourse of community energy as opposed to conventional energy planning recognizes that people have multiple ways of interacting with the energy system. Conventional energy planning restricts individuals to a passive consumer role (Outhred, 2000, Walker and Cass, 2007), while in community energy projects individuals are service users, green investors, beneficiaries, supporters and participants (Walker and Cass, 2007). However, despite the number of roles individuals play in community energy projects, a number of authors question their actual capacity to empower. Specifically, the high cost of investing in shares or paying a green tariff can increase inequality in a community by socially differentiating between those who can afford to participate and those who cannot. Barriers associated with the cost of renewable energy projects as discussed in Section 4.1.2.

Different communities have different dynamics. Some communities find it hard to develop the community capacity to take on a community energy project. Experience shows that a core team, key committed individuals or entrepreneurs are essential to success, as are supportive local institutions of various forms (Walker et al, 2007; DTI, 2000). Without such groups and individuals, there is simply not the capacity within a community to undertake the project. However, a major barrier to individuals and groups stepping up to be community energy project champions is time. People lead busy lives and developing a community energy project must compete with life factors such as work, family, friends etc (Outhred, 2000).

In Australia, as with many industrialised countries, electricity generation has been the remit of large centralized government or private enterprises, thus there is little experience of communities participating in the production of energy. This tradition results not only in institutional barriers (discussed in the political barriers section), but psychological and knowledge barriers as well. The major psychological barrier is that we already have access to reliable, quality electricity; people can flick on a switch and a light turns on (Charles, 2000). Given this provision of electricity, there is little incentive for people to get involved in a community energy project.

One of the major barriers to implementing community energy projects is a lack of knowledge, specifically:

- A lack of access to information, on how to start a community energy project;
- A lack of awareness around community energy project opportunities, including understanding the benefits of such projects and that communities can actually participate in electricity generation (CREA, 2006);
- Other technical and economic knowledge barriers detailed in the respective sections;
- A lack experience as very few people have undertaken successful community energy projects in Australia yet (Holmes A'Courte, 2009)
- A lack of knowledge in the broader community on how to get involved in the project and how it progresses (Vertical Project, 2001).

Unless the final knowledge barrier is adequately addressed, this can lead to back-lash within the community and counter the benefit of community cohesion. Community opposition to a project can be a significant barrier (Vertical Project, 2001), which is why community engagement must be one of the first steps in developing a community energy project.

#### 4.1.5. POLITICAL BENEFITS & BARRIERS

The literature also details a number of political benefits related to community energy projects which include:

- A likely increase in community involvement in the regulation and the evolution of energy legislation (Outhred 2000);
- Addressing government or market failure as co-operatives or community initiatives emerge out of said failures (Charles, 2000);
- Increase the security of energy supply (Thompson, 2008);
- Increased transparency in the development and management of energy projects (CREA, 2008);
- A reduction in the power of vested interests (CREA, 2006; Greenpeace, 2005; Outhred, 2000); and
- Increased public involvement in tackling climate change (Greenpeace, 2005), specifically in changing 'hearts and minds' (Walker et al, 2007) and the creation of stakeholders which give government a strong mandate to act on climate change (Holmes A'Courte, 2009).

While there are some benefits to the political economy of the Australian energy system associated with community energy projects, these are greatly outnumbered by the number of barriers that the political economy of Australia's energy system poses. Generally, international examples of micro-generation or distributed generation projects have not realised their income generating potential, due to regulatory barriers to market entry and grid connection. One example is the lack of incentive for network operators to connect to small generators (Walker, 2008; Shone, 2009). Particularly in the Australian energy sector since its deregulation, it is hard for small projects to negotiate favourable Power Purchasing Agreements; Victorian projects find it particularly hard due to the degree of energy privatization (Shone, 2009).

In Australia, Outhred (2000) suggests that an overarching barrier to energy co-ops is the narrow advice base for energy policy which focuses policy on a very narrow economic perspective. Specifically, the NSW energy legislation largely ignores the final consumer and does not empower or enable the consumer to be an active agent (Outhred, 2000). Another barrier is that responsibility for network economic regulation, technical performance of network service providers and environmental externalities are all split between state and federal or COAG levels (Outhred, 2000). This divided responsibility means that the electricity system is complex and difficult to navigate, with most policy focusing on “the big end of the game” (ibid), with little attention paid to distributed or community energy.

In addition, to the barriers in the energy regulation, there are barriers related to the regulation of organisations. For example, there is little familiarity and capacity within both communities and government departments to develop, incorporate and administrate co-operative models of governance and organisational structure (Jordan, 2000). This can result in delays (CREA, 2006) and poor management (Jordan, 2000). Particularly, the legislation governing co-operatives for example is extremely complex (Given, 2000) and they provide an additional hurdle for raising funds (Given, 2000)

#### 4.1.6. SUMMARY

In summary, it can be argued that the number of benefits associated with community energy projects identified in the literature, exceeds the number of barriers to their existence. One possible explanation for this is that most of the relevant literature is written by community energy advocates, and as such much of its emphasis is on selling the merits of community energy. Instead, opponents have taken to debating the technical and economic merits of various technologies, as community scale energy is not yet a dominant discourse within the Australian and global energy sector. Thus, I suggest that a STEEP analysis provides a more complex and richer picture into the barriers to and benefits of community energy projects, than currently available within the literature.

Within the barrier analysis there were gaps in the technical and environmental barriers, while the benefits across all STEEP factors were covered, with environmental benefits most frequently referenced. Also of note are knowledge barriers associated with many of the STEEP factors.

## 4.2. REVIEW OF AVAILABLE COMMUNITY ENERGY TOOLS

Having identified that there are a number of barriers to community energy projects, this section analyses the existing resources that assist community energy projects to overcome barriers. The purpose of this review is to identify which barriers, with a specific focus on knowledge barriers have not already been addressed to ensure that this research does not duplicate existing work.

The types of resources available to assist the development of community energy projects include, how to guides, case-studies, policy recommendations and energy modelling tools.

### 4.2.1. HOW TO GUIDES

There are a number of “how to guides” for community energy projects available, the most comprehensive is the UK Department of Trade and Industry (DTI) *Community Involvement in Renewable Energy Projects: a Guide for Community Groups* (2000). It provides a clear and concise guide to the development process for community energy projects and the different institutional arrangements and considerations. It includes financing options and options for legal structures such as co-ops and charities, but excluding ESCos. One of the most useful elements of the DTI guide is a flowchart (Figure 4) which maps of the different stages involved in setting up a community energy project, involving a share offer as the model of financing. This model is particularly useful for identifying at what temporal stage barriers occur and when solutions should be or could be implemented. Further, it identifies the likely stages which will influence the cost of a project. A similar resource is the Energy 4 All Step-by-step guide for communities who want to develop a community wind farm (Energy4All, 2007).

The Vertical Project (2001) is an investigation into the viability of one community energy project – the Castlemilk Urban Wind farm Energy Cooperative. It makes the social, environmental and technical case for the project and provides a series of steps and considerations that must be addressed. These include economic modelling, the planning development and the org-ware processes such developing a business plan and securing financing.

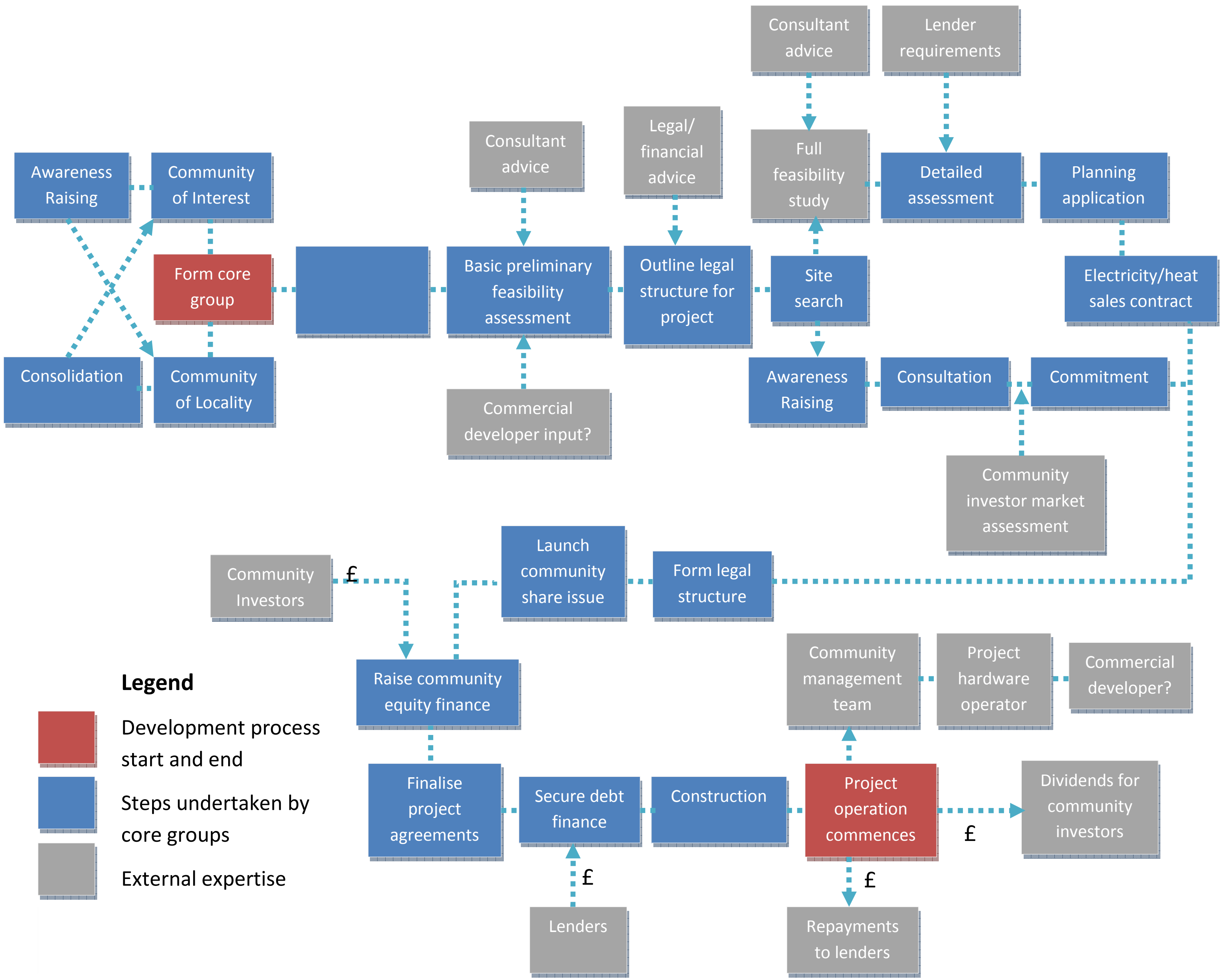



Figure 5: Flowchart of steps involved in setting up a community energy project including a share offer (DTI, 2000)

While all three guides detailed above are specific to the UK, they are still relevant to the Australian context and could be easily adapted... These guides are useful in overcoming most of the knowledge barriers – how to start a community energy project, the opportunities available and how to get the community involved, although technical knowledge is not specifically addressed. They also go some way to increase the capacity within communities about the institutional side of community energy projects. Finally, although it does not decrease the amount of time or money required, the flowchart (Figure 4) details funding options and gives potential energy proponents an idea of the time commitment required and how to source money which goes some way to overcoming the time and financing barriers.

#### 4.2.2. CASE STUDIES

There are many case studies available on the web; the Wind-Works website (Gipe, 2009) is a particularly good source, providing a wide range of articles and resources for co-operative and community wind projects. One useful report is Decentralised Energy in the Victorian Context (Thompson, 2008), which through four European case-studies, considers decentralised energy from a municipal council perspective. It gives an overview into the business models, technologies utilized, social and environmental impacts and the driving processes including policy that led to these different models of community/municipal energy projects. The key factors drawn from across the case study are evaluated and recommendations detailed for the Victorian context. Recommendations include, key policy drivers, technological applications, the need for municipal government leadership, economic and business models and community participation. Case studies such as these go some way to overcoming the knowledge barriers associated with developing community energy projects.

#### 4.2.3. POLICY RECOMMENDATIONS

Some of the most significant barriers to community energy are a result of the current Australian policy setting; a contrast to more favourable policies such as those in Denmark and Germany which facilitate the creation of community renewable energy projects. As such, there are number of reports which detail policy recommendations for communities to advocate, they include - *Community Power: The Way Forward* (CREA, 2006), *Australian Community Renewable Energy* (Hepburn Wind, 2009), *Decentralising Power: An energy revolution for the 21$^{st}$ Century* (Greenpeace, 2005) and *Meeting NSW Electricity Needs in a Carbon Constrained World: Lowering Costs and Emissions with Distributed Energy* (Dunstan and Rutovitz, 2009). CREA (2006) outlines a series of policy recommendations tailored to overcome specific financing and capacity barriers while the Greenpeace Decentralised Power Report gives a series of policy recommendations to increase the uptake of distributed energy more generally in the UK. A further example is provided by the Rutovitz and Dunstan (2009) which makes a series of policy recommendations to lower the cost and emissions for NSW electricity with distributed energy. The Hepburn Wind report builds on successful policies in the UK which involved creating community energy support teams which provided expert and advice and support (Walker and Devine-Wright, 2008). Specifically, Hepburn Wind (2009) proposes the creation of federally funded body – Australian Community Renewable Energy which would provide community energy projects with seed funding and support.

While these policy recommendations are useful for identifying how to overcome the political and knowledge barriers, they are only a first step. They provide a basis for an advocacy platform for community groups thinking of undertaking a community energy projects. However, it is the considered opinion of this researcher that communities should not have to rely solely on governments to overcome the barriers they face in developing energy projects.

#### 4.2.4. ENERGY MODELLING TOOLS

In the public domain there are many energy modelling tools available; a review undertaken by the Lawrence Berkeley National Laboratory (Gumerman et al, 2003) identified over 52 separate energy models available in North America and internationally and more have been developed since. A review undertaken by the Institute for Sustainable Futures (2009) suggests there are broadly three approaches to energy modelling:

- Planning and policy analysis models such as LEAP developed by the Stockholm Environment Institute (Heaps, 2008), D-CODE developed by the Institute for Sustainable Futures (Glassmire et al, 2009) and Next Generation Utility developed by the Rocky Mountain Institute (2009);
- Technology specific models such as the Community Wind Toolbox developed by Windustry (2008); and
- Location specific models, such as HOMER developed by the US National Renewable Energy Laboratory (2008).

Of these a limited number of the technology specific and location specific models are tailored to the community energy sector; examples include HOMER and the Community Wind Toolbox. HOMER is reviewed in more detail in Section 5.1.1.

These energy modelling tools provide technical information as well as the environmental and financial costs of benefits of community energy projects, thereby assisting communities to overcome technical knowledge barriers. However, there are two major limitations associated with these and other models – they either have limited scope or are pitched at the wrong audience. The Community Wind Toolbox for example is limited to wind technology and does not provide information on other available technologies. Conversely, while HOMER provides information on a number of different technology options, it requires the user to have a degree of technical knowledge that many community energy proponents do not have, particularly in the initial stages of developing a project

## 4.3. SUMMARY

These resources constitute a snapshot of the resources designed to overcome some of the barriers detailed in Section 4.1. In combination they are useful for overcoming the barriers of lack of awareness and access to information, community opposition and to a certain extent lack of technical and organizational capacity and knowledge in communities. It is important to note that both the barrier and available resources analysed were mainly based on international examples. This presents a gap in terms of barriers and resources specifically related to the Australian context.

Technical knowledge constraints were discussed in detail in Section 4.1.1; they represent a significant barrier to developing community energy projects. While there are a number of resources that aim to address knowledge barriers generally such as how to guides and technical knowledge barriers specifically, such as energy modelling tools and policy recommendations, none of them are designed for use by a wide range of community energy proponents looking to quickly identify appropriate technologies and associated costs and environmental impacts. As such, this research will focus on creating a method to assist in overcoming the initial technical knowledge constraints. In addressing this barrier, the term 'technical' is broadly defined to encompass not just technical factors associated with specific energy technologies, but also related environmental and economic considerations. To ensure that the method developed is appropriate for community energy proponents, a user analysis will be incorporated into the different stages of this research, as one of the consistent limitations of any technology or methodology is not considering how it will be implemented and by whom (Retnanestri et al, 2003).

# 5. TECHNICAL KNOWLEDGE ASSISTANCE TOOL DEVELOPMENT: METHODOLOGICAL REVIEW

Since there are no specified methods for overcoming technical knowledge barriers to community energy projects, a review of a number of relevant tools has been undertaken. Specifically, this chapter will examine two energy modelling tools and multi-criteria decision analysis processes and tools.

## 5.1. ENERGY MODELING TOOLS

As mentioned in Section 4.2.4, there are a number of energy modelling tools available. Of particular relevance to this research are HOMER and D-CODE.

### 5.1.1. HOMER

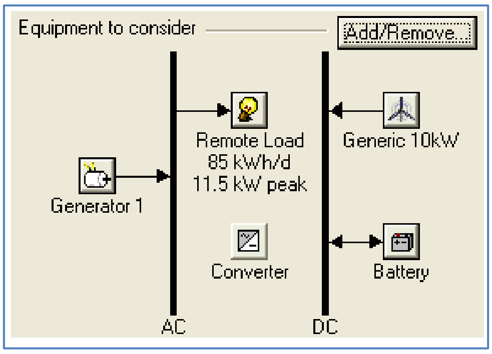



Figure 5: HOMER technical schematic (NREL, 2008)

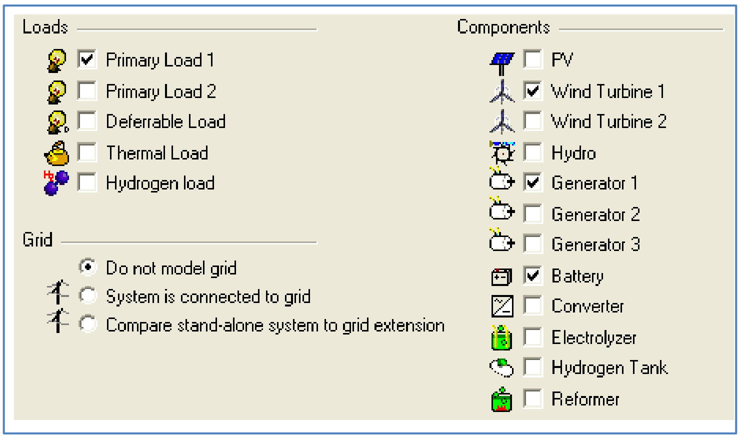



Figure 6: Technologies included in HOMER (NREL, 2008)

HOMER is a publicly downloadable micropower optimization model; it simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications (Gilman, 2004). Specifically, it generates a technical and economic analysis of multiple optimized energy systems, given specified energy loads. Figure 5 gives an indication of the technical schematic of the systems modelled in HOMER. The modelled energy systems can incorporate many different technologies (Figure 6), specifically:

- Batteries
- Biomass generators,
- Converters,
- Diesel generators,
- Micro hydro systems,
- Solar PV systems,
- Micro and mini wind turbines and

- Hydrogen fuel cells

The outputs generated by HOMER are shown in Figure 7 and include:

- Size of system (kW)
- Number of each technology included in the system
- Annual energy generation (kWh) and a comparison to energy loads
- Initial capital ($)
- Net present cost of system ($)
- Cost of energy ($/kWh)
- A breakdown of these outputs by each technology in the configured system
- Comparison charts and tables between different configurations

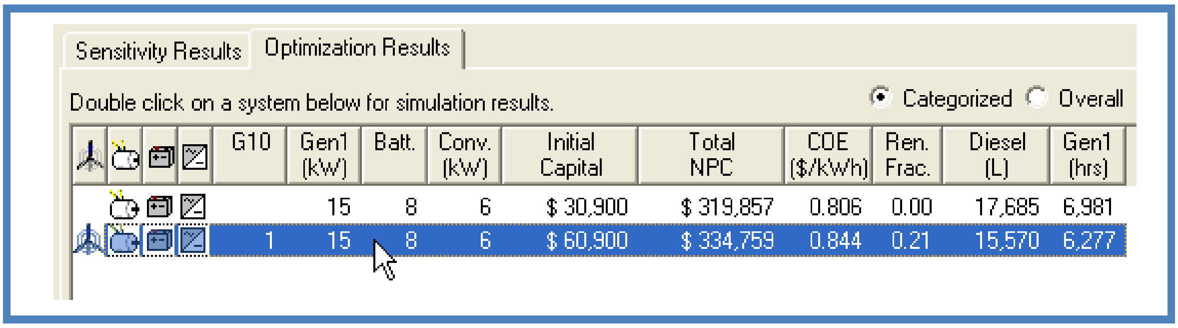


**Figure 7: HOMER Outputs (NREL, 2008)**

HOMER also enables the user to consider emissions and cost of emissions; constrain a number of the different variables; and undertake a sensitivity analysis to identify the factors that have the greatest impact on the design and operation of the system.

To produce this information it requires users to input:

- Detailed load (energy use) information;
- Costing information for each technology considered; and
- Resource inputs, specifically solar radiation, wind, hydro, and fuel for each hour of the year. For solar, wind, and hydro resources, either an import data file with 8760 hours of information or average monthly values are required (HOMER, 2008).

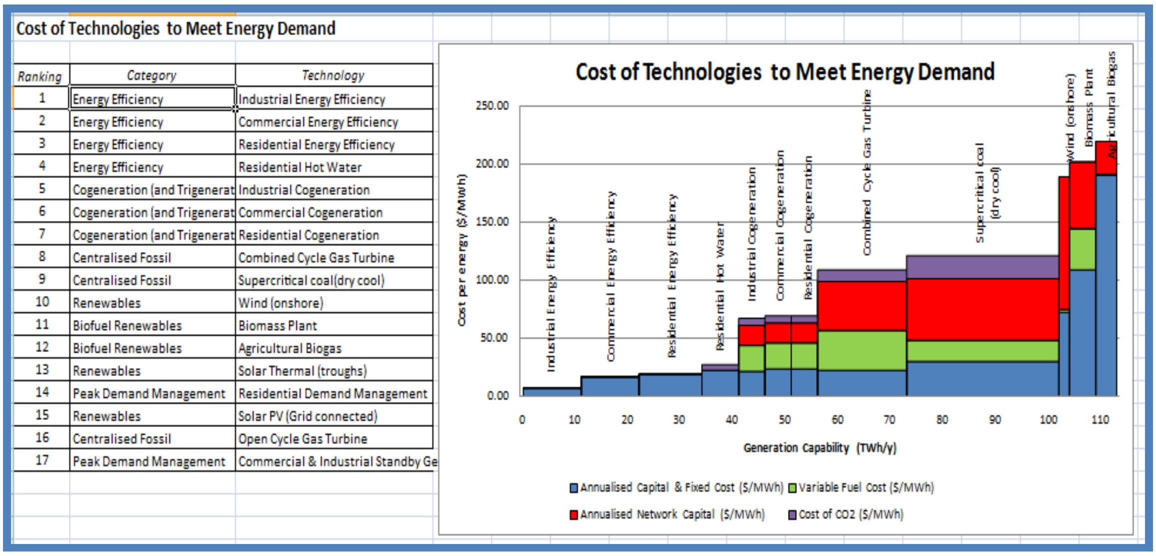
Thus, to use HOMER a large amount of information and a reasonable understanding of said information are required. So while HOMER produces reasonably reliable and sophisticated costing and technical information as well as proposing which technologies are most cost effective for a community given local resource availability, the knowledge entry requirements would likely prohibit many energy proponents from utilizing its services. Thus, the method developed to help overcome technical knowledge constraints to community energy projects must use simpler inputs and modelling processes. Nevertheless there are a number of useful features of HOMER which could be emulated in the methodology developed; these include:

- Use of multiple technologies
- The specific technical and economic output variables

### 5.1.2. D-CODE

The Description and Cost of Distributed Energy (D-CODE), which was created by the Institute for Sustainable Futures as part of the CSIRO Intelligent Grid Research project. Similarly to HOMER is a publicly available energy model. However, its purpose is as “a transparent, easily understood model that breaks down the true societal costs of energy generation” (Glassmire et al, 2009). It is primarily an economic model which compares technologies from a true cost perspective and is targeted at policy makers and energy planners. True cost incorporates capital, fixed and variable operation and maintenance, network and emissions costs. Specifically it ranks technologies in terms of cost and indicates their generating capacity in terms of both potential peak power (MW) and energy produced (MWh/year) as shown in Figure 8. All told there are currently 20 technologies incorporated into D-CODE; they broadly fall into the following categories:

- Renewable energy technologies (centralised and distributed)
- Centralised fossil fuel generation technologies
- Distributed technologies (including cogeneration); and
- Energy Efficiency and Peak Demand Management programs (ibid)


Cost of Technologies to Meet Energy Demand

| Ranking | Category | Technology |
|---|---|---|
| 1 | Energy Efficiency | Industrial Energy Efficiency |
| 2 | Energy Efficiency | Commercial Energy Efficiency |
| 3 | Energy Efficiency | Residential Energy Efficiency |
| 4 | Energy Efficiency | Residential Hot Water |
| 5 | Cogeneration (and Trigenerat | Industrial Cogeneration |
| 6 | Cogeneration (and Trigenerat | Commercial Cogeneration |
| 7 | Cogeneration (and Trigenerat | Residential Cogeneration |
| 8 | Centralised Fossil | Combined Cycle Gas Turbine |
| 9 | Centralised Fossil | Supercritical coal(dry cool) |
| 10 | Renewables | Wind (onshore) |
| 11 | Biofuel Renewables | Biomass Plant |
| 12 | Biofuel Renewables | Agricultural Biogas |
| 13 | Renewables | Solar Thermal (troughs) |
| 14 | Peak Demand Management | Residential Demand Management |
| 15 | Renewables | Solar PV (Grid connected) |
| 16 | Centralised Fossil | Open Cycle Gas Turbine |
| 17 | Peak Demand Management | Commercial & Industrial Standby Ge |



**Figure 8: D-CODE Technologies ranked by cost per MWh**

As a meta policy tool D-CODE does not incorporate any location specific technical or economic inputs, instead Australian wide averages are used, and where Australian data is unavailable, international information has been incorporated. As such D-CODE does not help people design energy systems.  However there are a number of features of the model that make it relevant to this research; they include:

- Incorporation of multiple distributed energy technologies likely to be relevant to the community energy sector;
- Easy to access technical factors (for example life span of a technology) as well as up-to-date Australian costing and emissions information about said technologies; and
- Simple and transparent economic and energy modelling processes using an Excel platform.

Considering these two energy models in more detail indicates that there is potential to create a tool that uses the simplicity of the D-CODE model for a similar purpose to HOMER. Specifically, one that provides initial information about technological viability for a specific community, noting the fundamental trade-off that by simplifying the inputs and modelling process the accessibility is increased but accuracy is diminished.  It is important given this purpose that any tool developed similarly to HOMER and D-CODE incorporates multiple technologies.

## 5.2. MULTI-CRITERIA DECISION ANALYSIS

In addition to the tools developed specifically for the energy sector, there are frameworks and tools developed by other sectors that could be modified to be of use to the development of community energy projects.  In this review, multi-criteria decision analysis (MCDA) is explored, typified by two tools developed for the water industry – the *Water Services Association of Australia (WSAA) Sustainability Framework* (Lundie et al, 2008) and the *Environmental Sustainability Assessment Tool* (ESAT) (SAP, 2008) developed by the Centre for Water and Waste Technology and the Sustainability Assessment Program (SAP), UNSW.

In traditional energy decision modelling processes, economic indicators are usually the primary factor, for example in both HOMER and D-CODE scenarios or technologies are ranked by cost.  However, across the sector, particularly in community energy projects multiple and often competing objectives are important to the final decision as to which projects are pursued.  Multi-criteria decision analysis (MCDA) is a structured approach and a set of techniques for aiding decision making through balancing a number of objectives (Lai, 2008; DCLG, 2009).  It provides decision makers with a process for organising and synthesising large amounts of monitory and non-monetary information.  It does not however provide the “right” answer or an “objective” analysis (Lai, 2008) but instead enables the disaggregation of a complex problem, allows data and judgements involved in evaluating these disaggregated pieces to be made explicit and then a reassembles the pieces to present a coherent overall picture (DCLG, 2009).

Generally, the purpose of a MCDA process is used to model and evaluate options to fulfil a specific requirement; however it can be structured to meet more nuanced purposes, including:

- showing decision makers the best way forward;
- identifying the areas of greater and lesser opportunity;
- prioritising options;
- clarifying the differences between options;
- helping the key players to understand the situation better;
- indicating the best allocation of resources to achieve the goals;
- facilitating the generation of new and better options;
- improving communication between parts of the organisation that are isolated; or
- any combination of the above (DCLG, 2009).

There are broadly seven key steps involved in an MCDA process:

1. Define context specific objectives
2. Generate options
3. Select criteria
4. Assess the performance of each option for each criteria
5. Assigning weightings to each criteria
6. Generate a total weighted score for each option
7. Examine results, refine the process and generate recommendations

It should be noted that different sources aggregate these steps in different ways; for example the WSAA framework identifies six phases (Lundie et al, 2008), while the Multi-criteria analysis manual specifies eight stages (DCLG, 2009).

Step 1: Defining context specific objectives

This process entails establishing the scope, process and purpose of the MCDA, which in turn depends on identifying key players or stakeholders and their needs and knowledge. Then based on these considerations determine specific objectives for the project to which the MCDA is to be applied.

Step 2: Generating options

To fulfil any need there are always different options. The process of generating options is important as they become the basis of the MCDA and the final recommendation. DCLG (2009) suggests that the best way to undertake the first two steps is through a facilitated workshop, as workshops foster creativity, non-obvious options and share knowledge across stakeholders.

Step 3: Select criteria

According to DCLG, assessing "options requires thought about the consequences of the options, for strictly speaking it is those consequences that are being assessed, not the options themselves" (2009). The criteria in an MCDA process are consequences that achieve the objectives specified in Step 1 and must be quantifiable. For example, if an objective is to reduce a community's contribution to climate change, the criteria would likely be carbon emissions generated or saved. There are always many potential criteria, determining the most useful to use will depend on judgements made by the group and the input capabilities (Lundie et al, 2008) i.e. what information is available within the scope of the process.

Step 4: Assess the performance of each option

For each criterion the performance of each option is determined and a performance matrix compiled. This process may entail extensive modelling and research to determine the performance, for example life-cycle analysis or may be a judgement call made by specific stakeholders for example assigning a number based on the relative aesthetic of a technology.

To compare the performance of options across different criteria there are a number of techniques. The most commonly used is the linear additive approach which combines the performances of an option across all criteria into one overall value (Lundie et al, 2008, DCLG, 2009). This entails assigning a comparable score to each of the values in the performance matrix. To do this scales are constructed. Typically, for a specific criterion the most preferred option is given a score of 100 and the least preferred is assigned a score of 0, while the remaining options are assigned a score in-between, relating to the strength of preference (DCLG, 2009). There are a number of approaches for assigning scores including min-max, ranges and fuzzy method (Lai, 2008). The min-max and ranges approaches are discussed more in Section 7.3.

Step 5: Assigning weightings to criteria

The second element of the linear additive approach involves assigning a weighting to each criteria. This is usually done either through ranking or direct weighting (Lai, 2008). In a ranking approach a stakeholder process is undertaken to rank the importance of the criteria and the ultimate ranking corresponds to a weight. Applying a direct weighting approach, involves stakeholders assigning a direct weight to each criteria based on its relative importance to the final outcome. Lundie et al (2008), emphasise the need for simplicity and transparency in this process, while DCLG states that the process of deriving weights is fundamental to the effectiveness of an MCDA as they represent the views of the people involved in the process.

Step 6: Generating a total weighted score for each option

The linear additive method is ultimately defined by Equation 1, which generate a total weighted score ($S_i$) for each option ($i$) by combining the performance scores from Step 4 ($s_{ij}$)and the criteria ($j$) weights from Step 6 ($w_j$).

**Equation 1**

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} = \Sigma w_i s_{ij}$$

Step 7: Examining the results, refining the process and generating recommendations

This process includes, discussing the outcomes of the MCDA, performing sensitivity analysis on the results and generating recommendations for ways to move forward, essentially wrapping up the process and ensuring that it has been useful.

### 5.2.1. WSAA FRAMEWORK

The above explanation of MCDA processes refers to the *WSAA Sustainability Framework*. Specifically, it is a "methodology for evaluating the overall sustainability of alternative options for urban water systems" (Lundie et al, 2008). The WSAA Sustainability Framework is relevant to the research question of how to overcome technical knowledge barriers to community energy projects, as it outlines and demonstrates that a MCDA process is a sound structure for generating and understanding technical information.

However, the WSAA Framework is tailored to a utility, as such the timeframe and detail required for each community energy project team to undertake such a process is likely to be prohibitive.

### 5.2.2. ENVIRONMENTAL SUSTAINABILITY ASSESSMENT TOOL

Another MCDA tool available is the Environmental Sustainability Assessment Tool (ESAT) (SAP, 2008). Using an Excel platform ESAT is designed to help Melbourne metropolitan water service providers compare alternative water and sewerage options (ibid). The user interface allows the input of two different water and sewage scenarios partially shown in Figure 9. The inputs include local context information and different technology options. Using this input data, ESAT completes a quantitative life cycle assessment (LCA) and life cycle costing (LCC), the results of which are then consolidated in a MCDA table (ibid).

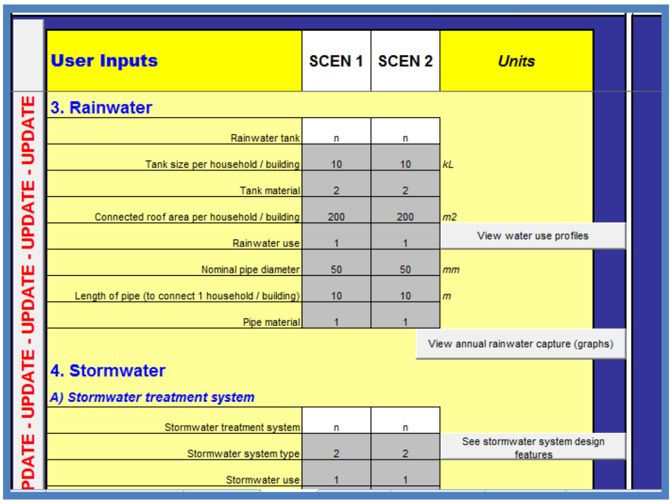



Figure 9: ESAT User Interface (SAP, 2008)

Notable modelling features of ESAT that enable this process include:

- An interactive map, which allows users to provide location specific variables by indicating where the project is in Melbourne (Figure 10);
- Modelling of water demand and matching it to different water supply options;
- An interactive MCDA process, that enables users to modify the weightings of particular variables (Figure 11); and
- Outputs calculated which become the criteria used in the MCDA. The specific criteria used are energy, water use, greenhouse emissions, footprint and nutrients as well as LCC (Figure 11).

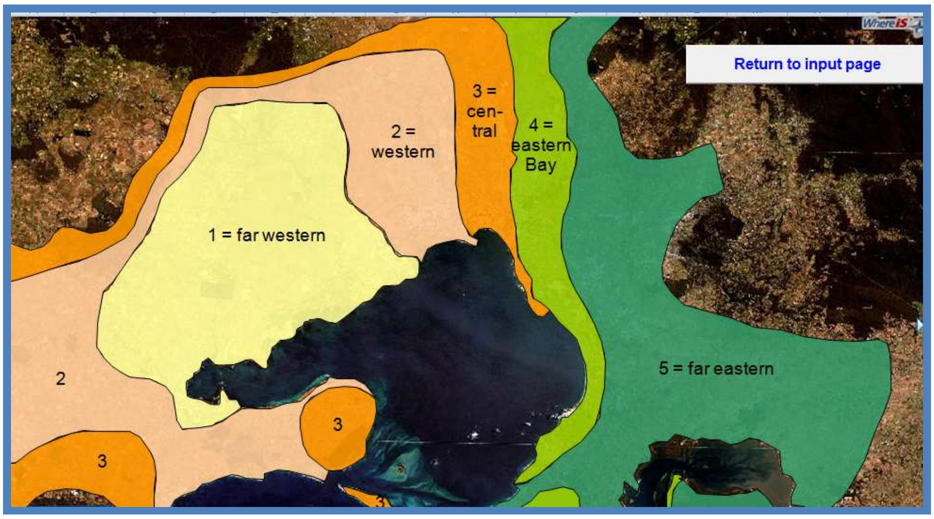



Figure 10: ESAT Interactive Map of Melbourne (SAP, 2008)

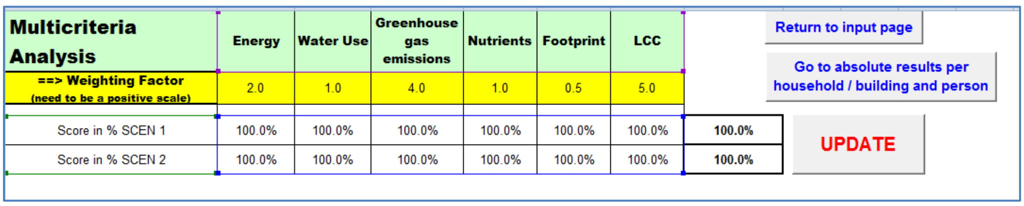



Figure 11: ESAT Interactive MCDA (SAP, 2008)

The ESAT is essentially a tool that facilitates the overarching MCDA process, specifically Steps 4-6. It calculates results which provide the basis for users to undertake step 7 the discussion and final decision recommendations. For steps 1-3 ESAT assumes meta-objectives, incorporates the criteria listed above and has a wide range of technology options available; for example rain water tanks and storm-water reuse. However, the user interface is designed for flexibility, so users can specify which options and criteria are relevant based on their context specific objectives and information.

A tool with similar functionality and many of the features of ESAT applied to the community energy sector has the potential to assist communities in overcoming technical knowledge constraints. It could do this by identifying technologies with greater or lesser potential for a community and help community energy proponents understand their situation better by providing useful technical, economic and environmental information. However, it is important to note the level of data required to complete a comprehensive LCA and LCC on many energy technologies is beyond the scope of this thesis.

## 5.3. SUMMARY

In summary, although applied to the water sector ESAT and the WSAA framework are particularly useful in showing the power of the MCDA process and what can be done in a simple Excel platform. The energy models reviewed – D-CODE and HOMER provide a starting point for the creation of an energy modelling tool that draws on the simplicity and transparency of modelling used in D-CODE and the location specific nature of HOMER. These tools and the information gathered in the following technological review will become the basis for creating a tool that incorporates energy modelling and MCDA processes to assist communities to overcome technical knowledge constraints.

# 6. TECHNICAL KNOWLEDGE ASSISTANCE TOOL DEVELOPMENT: TECHNOLOGICAL REVIEW

Before embarking on a process of developing a community energy tool, it is important to understand the technologies suitable for community energy projects and thus which ones should be included into CEDAT. As such, a review of the commercially available energy technology hardware[1] has been undertaken. This chapter will first discuss what makes energy technologies suitable for a community energy project and then review four technology categories that have the determined attributes.

## 6.1. FEATURES OF APPROPRIATE COMMUNITY ENERGY TECHNOLOGIES

Of the three defining features of a community energy project – low carbon, distributed and democratic, the first and second have significant bearing on which technologies may be appropriate. Specifically, the technology must utilise renewable energy sources or if it utilises fossil fuels, it must result in emissions significantly lower than conventional coal, oil or gas fired electricity. Also the technology must be able to be deployed at a scale that is appropriate to providing a community with energy. In determining the scale-range of technologies appropriate, Rutovitz and Dunstan's (2009) definition for distributed energy is useful - "energy solutions which occur within the low voltage network and so do not use the high voltage transmission network". This definition supports the proposed scale range for community energy projects discussed in Chapter 2 (tens of kilowatts to tens of megawatts). Based on this definition, Rutovitz and Dunstan (2009) suggest that appropriate technologies include energy efficiency programs, distributed generation and load management. While energy efficiency and demand management are important elements of community response to making energy systems more sustainable and should be considered when undertaking any community energy project, they are beyond the scope of this research, which will focus on energy generation technologies.

An additional factor to consider when determining appropriateness of a technology is its stage of development. MacGill (2008) suggests that there are three main stages of technological innovation – invention, commercialisation and diffusion/adoption. I propose

[1] The International Institute for Applied Systems Analysis' (IIASA) Transition to New Technologies Program defines technology as
Technology = Hardware + Software + "Orgware"
Where hardware is the manufactured objects, software is the knowledge required to design, make and use the hardware and "orgware" is the institutional arrangements that enable the generation and use of the hardware and software (IIASA, 2009).

that to be used in community energy projects, a technology must be at least in the commercialization stage. Thus, in addition to technically mature technologies, new emerging technologies into the market would be suitable, *if* they have already been installed successfully. However, technologies still in the research and development (invention) stage of technical innovation are not included, as they represent too high a risk for communities to take.

Walker and Cass (2007), suggest that the function of community energy projects varies from producing useful heat or electricity for local consumption or to be fed into the grid. Within the community energy project literature two technological options dominate the delivery of these services. The body of literature concerned with *co-operative models* of community energy projects (Walker, 2008; Vertical Limit, 2001; CREA, 2006; Greenpeace, 2005) focus on wind power as the technology of choice. Conversely, the literature which considers ESCos (Thompson, 2008; Greenpeace, 2005) focuses primarily on combined heat and power or cogeneration technologies, although photovoltaics and energy efficiency programs are also mentioned.

Two reports outline proposed appropriate technology options for community application. Walker and Cass (2007) in the UK suggest solar, wind, hydro, biomass and heat pump technologies are suitable, while MMA (2009) suggest Australian community energy projects should use on and off grid solar PV, wind, micro hydro and biomass. Based on these reports, the definition of community energy used in this research and knowledge of existing proposed community energy projects in Australia, the technologies reviewed are wind, solar PV, cogeneration and trigeneration and sustainable biomass.

Solar thermal power technologies were initially included in the review as they have great potential in Australia due to our excellent solar resource (Lovegrove and Dennis, 2006) and could have community applications (Becker et al, 2002 in Romero-Alvarez and Zarza, 2007). However, given the lack of publicly available site specific modelling information (i.e. how energy generation tracks to solar resource), and that currently the majority of applications being considered are centralised power stations, solar thermal is not incorporated into this research. The initial review undertaken can be found in Appendix A. Other technologies not considered, due to time constraints, include solar hot water and ground source heat pumps as they are household scale technologies; and microhydro technologies and geothermal district heating networks.

The review not only considers technology hardware and what is technically possible, but the associated social, economic, environmental and political considerations that combine to determine whether a technology is viable in a particular community. For example, renewable energy technologies rely on environmental constraints such as sun and wind. Specifically, costs including capital cost and operation and maintenance costs, barriers and benefits, state of the industry and current community applications are discussed. However, the 'orgware' of the projects are not considered, having already been discussed in Section 2. The technical considerations reviewed include technology hardware available, capacity factors, scale, energy generation potential, siting considerations and more.

## 6.2. WIND

### 6.2.1. DESCRIPTION

Technologies have been developed to harvest the energy in the wind for millennia. In the contemporary wind industry, the standard technology used to harness wind power to produce electricity is a three-bladed (or rotor) horizontal axis, upwind, grid connected wind turbine (Figure 12) (IEA, 2008; SEDA, 2002). These work in the most basic terms by wind turning aerofoil blades, which in turn drives a generator which produces electricity that is then fed into the grid (Riedy and Lewis, 2007). The aerofoil shape means that as the wind speed increases there is a greater zone of negative pressure on the upper side of the turbine rotor, creating a suction force, which increases blade rotation speed and thus electricity produced (Kaye, 2008).

### 6.2.2. TECHNICAL CONSIDERATIONS

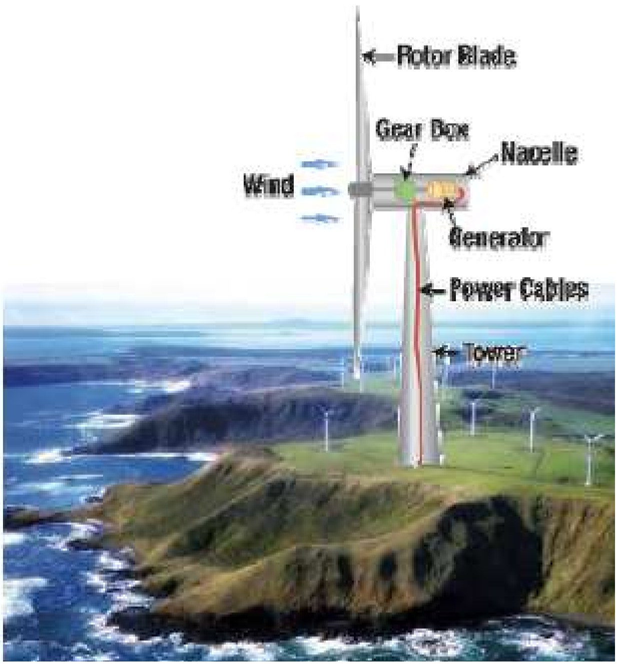



**Figure 12: Wind turbine schematic (Kaye, 2008)**

Modern wind turbines include rotors, a hub which houses the generator and a tower (Figure 12). Specific technical considerations of these turbines include scale, efficiency, wind regime, siting considerations and energy output.

**Scale**

The scale of a wind farm is determined by two factors, the size and thus rated power output of a wind turbine and the number of wind turbines in the farm. This makes wind one of the most easily saleable technologies available.

Currently, wind turbines range from micro 400W domestic systems to mini-wind 10KW turbines, to utility scale 0.5-2.5MW turbines and very large offshore 5 or 6MW turbines. These power classifications (MW) are assigned values associated with the rated power of a turbine, which in turn relates to the rotor diameter of a turbine. Figure 13 shows the different rotor diameters and how they relate to power classifications.

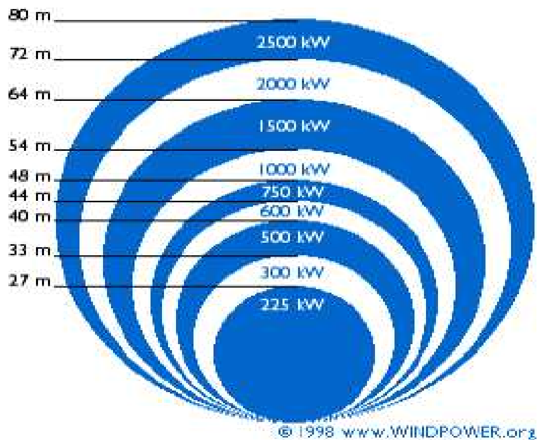



**Figure 13: Rotor diameters of different sized large wind turbines (Kaye, 2008)**

**Efficiency**

The efficiency of wind as a technology is more complex than fossil based energy. It is dependent on both the efficiency of the turbines and wind regime. Turbine efficiency is the ability of the technology to translate wind energy into electrical energy. According to Diesendorf (2007), large wind turbines covert into electricity about 45% of the wind passing through the swept area of the blades, however, the maximum theoretical efficiency of a wind turbine is a Betz Limit of 59% (Kaye, 2008).

**Wind Regime**

Electricity generated by a wind turbine depends on wind regime. The most important factors associated with the wind regime are average wind speed and wind speed variability, air density, and type of flow.

Most wind turbines commence power generation at wind speeds of approximately 3.5m/s; they produce maximum power output at approximately 13m/s and 'cut out' at wind speeds in excess of 25m/s (Hepburn Wind, 2008). See Figure 14 for the profile of electricity produced at different wind speeds.

Type of air flow - laminar or turbulent is also important as turbulence reduces energy yield and increases blade ware. Sites that are considered to have a good wind resource have an annual mean wind speed of approximately 7m/s; excellent sites have an annual mean wind speed of 8m/s (Johnstone, 2003 in Diesendorf, 2007). According to Diesendorf (2007) most good sites in Australia are on inland pasture, this differs from Riedy and Lewis' (2007) assessment which suggests that most good sites are in coastal and mountainous areas.

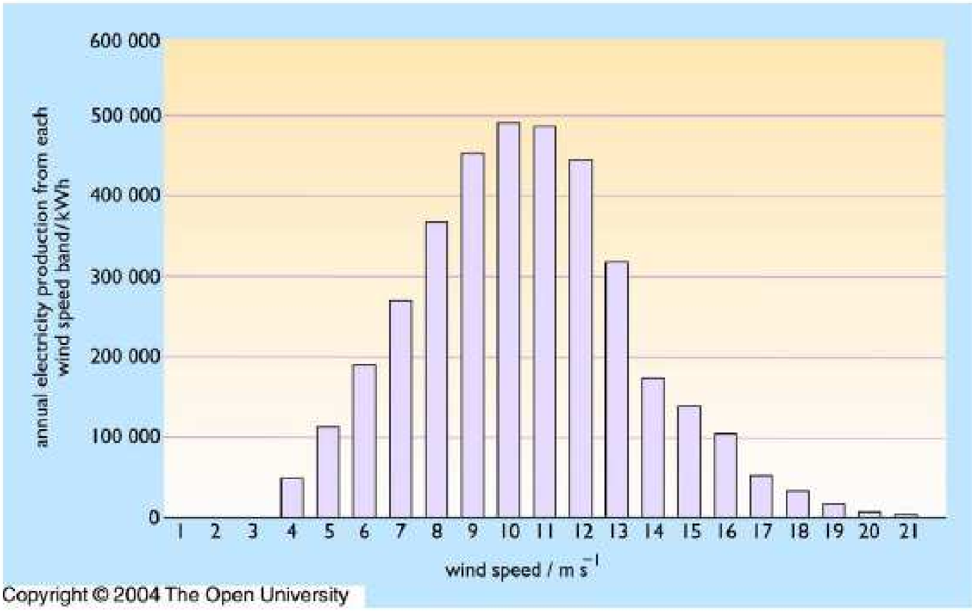



**Figure 14: Annual electricity production at different wind speeds (Open University, 2004 in Kaye, 2008)**

Capacity factors are the ratio of energy a technology produces compared with what it could produce at maximum power. They are standard industry values associated with specific technologies or sites and give an indication of the technical appropriateness of a site or technology. Specifically, it considers the variability of wind speed and thus power output. For example, in Australia, the typical wind capacity factor is approximately 35% (MMA, 2007), which is considered a good resource by global standards (Diesendorf, 2007).

**Siting considerations**

Siting is perhaps the biggest constraint to wind as a technology. There are many important factors to consider to appropriately siting a wind farm. These factors include:

- Wind speed and turbulence, as discussed above. Siting considerations related to good wind resources include:
    - Having few to no obstacles in front of the wind farm in the direction of flow; and
    - A smooth surface leading up to the turbine, as surface roughness slows the wind and introduces turbulence (Kaye, 2008).
- Area needed. Gipe (2009) suggests that the area needed is 20ha/MW or 80-100m$^2$ of land area/m$^2$ rotor swept area. NREL (2009) provides an online calculator for

estimating the amount of land area required. Although it is important to note that most of this land area can have multiple purposes.

- Proximity to electricity distribution or transmission network. This is predominantly to do with cost, although transmission losses may also be a factor.
- Local environmental considerations. If badly sited, wind farms can have quite a significant impact on local bird and bat populations, which is why it is important to site wind farms in areas which are not of ecological significance. Estimates of typical bird deaths due to a wind turbine are less than 5 per year (Riedy and Lewis, 2007).
- Amenity considerations. Aesthetic and noise considerations associated with wind farms have proven to be significant barriers to wind farm development. At a distance of 350m the sound of a wind farm is roughly equivalent of the sound of a busy road 5km away (Riedy and Lewis, 2007), while wind farms can be viewed from long distances.

These siting considerations, if not adequately addressed have proven to be significant economic, technical, environmental, political and social barriers to wind as a viable technology.

**Energy output**

Electricity output from a wind turbine depends on three main variables already discussed – rotor swept area and air density and wind velocity over time, which in turn depends on wind regime at the site, turbine height and the efficiency of the turbine (IEA, 2008). Wind literature (NREL, 2005; Gipe, 2009; Kaye, 2008; Windustry, 2009; USDA, 2009; SEDA, 2002) details a number of different equations and approaches to modelling wind energy output, depending on purpose of modelling i.e. degree of accuracy or simplicity required. These approaches are discussed in more detail in Section 7.2.

### 6.2.3. COST

The typical cost variables considered in determining whether to pursue an energy project are:

- capital cost - the amount of money required to get a project off the ground; and
- unit cost - the cost it takes to produce one kilowatt hour of useful energy (heat or electricity).

Unit cost is determined by three main factors – lifetime of the project, capital costs and operation and maintenance costs (O&M), also taking into account the time value of money. Network and planning and development costs (ancillary services) also contribute to the cost of the project. The lifetime of a wind turbine is typically taken as 25 years (MMA, 2007), while there are multiple different capital and O&M costs sited in the literature.

One of the biggest challenges in this research has been to find comparable economic data for each technology, as wind industry reports use different assumptions and variables to solar industry reports and bioenergy industry reports. As such, this research draws its primary costing data from Australian reports that compare the economics of different energy technologies. Examples include *Impacts of a community based fund to develop renewable energy generation*, *Report to Australian Community Renewable Energy* (MMA, 2009), *Impacts of Deep Cuts in Emissions from Electricity Generation: Assumptions and Methodology* (MMA, 2007)*, Distributed Energy Solutions* (SEDA, 2002) and *Net employment impacts of climate change policies* (Access Economics, 2009). The cost figures for wind in these reports are detailed in Table 1. The most recent figures are more expensive, which is likely a result of more data based on recent experience and because the best wind sites will already have been developed.

**Table 1: Wind costs**

| Source | Project Size (MW) | Capital ($/kW) | Fixed O&M ($/kW/y) | Variable O&M ($/MWh) | Fuel ($/MWh) | Network ($/kW) | Ancillary Services ($/MWh) | Baseline year |
|---|---|---|---|---|---|---|---|---|
| MMA (2009) | ≤4 | 2500 | --- | 5 | 0 | 50 | 10 | 2009 |
| SEDA (2002) | ---[2] | 1800 | --- | 10[3] | --- | --- | --- | 2002 |
| Access Economics (2009) | --- | 2400 | 20 | 1.09 | --- | --- | --- | 2008 |
| MMA (2007) | 115 | 1822 | 35 | 2 | 0 | 100 | 5 | 2010 |

From the number of blank cells in Table 1, it is clear that when comparing these reports finding comparable economic data still represents a challenge. As such one of these reports will be used preferentially to ensure consistency. However, one of the limitations associated with using the above economic data is that it is a single point data referenced against a specific wind project size; as such the data do not take into account economies of scale.

Given that different sized wind projects could have different community energy applications, it is important to consider the cost of mini-wind projects (kW) as well as larger co-operative sized projects (MW) as given in MMA (2009). NREL (2005) states that the cost

[2] --- indicates no data was provided

[3] In the SEDA (2002) report, the term marginal cost was used instead of variable cost. The difference between the two terms is that marginal cost includes fuel costs while variable cost does not.

of a typical 10kW wind turbine installed is approximately AU$37,000 or $3700/kW, which is significantly more – at least $1200/kW – than large scale wind turbines. However O&M costs for small wind turbines are estimated at $60/year.

Based on more detailed analyses of costs and the electricity output, typically the unit cost of large scale wind in Australia varies from 7.5c/kWh for large-scale wind farm with an excellent wind resource (Diesendorf, 2007), to around 11c/kWh for a small wind farm such as the Hepburn Wind Farm (Hepburn Wind, 2008). Any tool created that provides information about the suitability of different energy technologies for a community, would calculate unit cost, however these are good reference points.

### 6.2.4. BARRIERS & BENEFITS

Existing barriers to wind in addition to the siting issues discussed above include:

- Intermittency. Turbine output varies with the wind resource. This variability or intermittency can be challenging for grid systems at high penetration levels, the degree depending on the flexibility of the electricity system as a whole (IEA, 2008). One mechanism to overcome this barrier is the deployment of new storage, network operation and transmission technologies (ibid)
- Forecasting. Current wind forecasting techniques are not yet sophisticated enough to maximize the integration of wind energy into the grid. Better long term and real-time wind forecasting techniques are needed (Kaye, 2008)
- The need for remote monitoring and control of wind farm output (Riedy and Lewis, 2007)

These factors, all mean that wind is quite a complex technology for communities to manage; as such often management is outsourced. However, the maintenance of a wind farm is not particularly complex and local labour could be trained in the necessary skills, providing additional jobs in the community.

Another barrier to wind is the current political environment in Australia. For example in 2006, the Federal Environment Minister invoked the *Environment Protection and Biodiversity Conservation Act 1999* to ban the Bald Hills wind farm in Victoria, only the fourth time that the act had been used to refuse any development proposal (Diesendorf, 2007)

However, there are significant benefits to wind technology. These include the fact that "wind turbines need no fuel, incur almost no $CO_2$ emissions and, on completion of the permitting process, can be installed relatively quickly" (IEA, 2008). In addition, they also have low water needs (IEA, 2008) and can lead to investment in rural communities (SEDA, 2002). Wind occupies less land area per kWh of electricity generated than any other energy conversion system, apart from rooftop solar and is compatible with grazing and almost all crops (Diesendorf, 2007). Significant technology advances are also expected to continue, partly driven by the move to large offshore installations.

### 6.2.5. WIND INDUSTRY AND COMMUNITY APPLICATIONS

Wind is the fastest growing energy technology in the world, growing at over 25% per year averaged over the past 20 years (Diesendorf, 2007). In Australia, the installed wind capacity as of 2008 contributed 2504GWh of electricity to the grid annually, which accounts for about 1.2% of Australia's total electricity demand (IEA, 2008). However, this is a relatively small amount compared with the total installed capacity in Germany the US, India and China and the proportional amount that wind contributes in Denmark.

Wind technology is the basis for a significant proportion of the community energy projects world-wide. The only Australian example is the proposed Hepburn community wind farm in Daylesford, Victoria which has raised sufficient funds to order two 2MW turbines that are predicted to produce 12,200MWh of renewable energy per year. Internationally, community energy wind projects currently range in size from the largest the Middelgurnden 40MW offshore wind-park, owned by a co-operative of more than 7000 members (Christianson, date unknown) to individual mini-wind turbine initiatives. It is important to not that there is a significant different in the type and cost of a community energy project based on the scale of the wind turbine used. As such, this research will consider two wind options – mini-wind turbines, for small community applications and utility scale wind turbines for larger communities.

Wind is particularly suited to community applications given its cost relative to other renewable energy technologies, its modularity, specifically that it can be scaled to the size of the community or the financial resources available and that it decarbonizes a community's energy supply. It is also a proven technology commercially and in community applications and has publicly available information that can form the basis of an energy model, which relates energy generation to cost based on locational factors. The important locational factors identified for wind are wind speed and sufficient land availability.

One drawback for wind in a community application is that it is not suitable technology in isolation for communities intending to become energy self-sufficient. This is due to issues of intermittency. As such wind must be either connected to the grid or an energy storage system. For grid connected projects such as Hepburn Wind this means while communities own wind turbines, their homes are not directly powered by said turbines, as such grid connected wind only goes some way to localise and democratise energy supply.

## 6.3. SOLAR PHOTOVOLTAICS

### 6.3.1. DESCRIPTION

Solar photovoltaic (PV) technology converts sunlight into direct current (DC) electricity using semi-conductor cells of crystalline silicon wafers. There are different silicon wafer technologies including polycrystalline, micro-crystalline and amorphous silicon. Although materials other than silicon can also be used, examples include, cadmium telluride, and copper indium selenide/sulphide (Jacobson, 2008). Conventional flat-plate PV modules consist of about 40 solar cells, 15cm in diameter and 0.3mm thick, connected together behind glass plate (Diesendorf, 2007). These modules can be mounted on roofs or combined into farms.

It is often necessary to convert the electricity generated by PV systems from DC to AC using an inverter so that it can be used to power household and other appliances and connected to the grid. Additionally, in off-grid or stand alone applications PV systems are usually coupled with an energy storage system such as lead-acid batteries.

### 6.3.2. TECHNICAL CONSIDERATIONS

There are a number of key technical considerations for solar PV systems; these include, scale, efficiency, annual capacity factor, siting/location considerations.

**Scale**

Because PV systems are modular, with a typical single module size of 80W, requiring an area of 0.73m$^2$ (SEIA, 2009) they can essentially be scaled to any size, given space constraints. According to Jacobson (2008), solar PV farms world-wide range in size from 10–60MW although proposed farms are on the order of 150 MW; while typically residential PV systems are around the 1-5kW scale.

**Efficiency**

Currently crystalline silicon modules have an efficiency of 15% (projected to increase to 25-28% by 2050), while thin-film PV technology has a slightly lower efficiency at 11% (IEA, 2008).

**Siting considerations**

The power output of a solar panel is dependent on the angle of the sun and the intensity of the insolation, which is related to geographical location (latitude) and cloud cover. Important factors when siting PV systems include inclination of the panel at a given time of year or day which is dependent on the latitude and peak sun hours of the specified location.

**Energy generation**

There are multiple modelling techniques, tools and guidelines available to calculate energy generation from a solar PV system based on location with greater and lesser degrees of sophistication. These are discussed in Section 7.2.2.

**Capacity Factor**

The typical capacity factor for centralised solar PV farms is 20% and 15% for household systems (MMA and The Climate Institute, 2008). This is to do with the limited hours of operation of solar PV.

### 6.3.3. COST

The lifespan of a PV system is typically 25-years (Diesendorf, 2007). Table 2 gives the current costs of PV systems of different scales under different applications. This shows that off-grid systems are much more expensive due to the need for energy storage systems. It is also interesting to note that economies of scale are captured at a low size threshold (10kW), as unlike wind power, electricity from PV does not become significantly cheaper as the scale of installation is increased.

**Table 2: Current costs of PV systems at different scales under different applications (Watt, 2005)**

| Category/size | Cost ($/W)[4] |
|---|---|
| Off-grid <=1kW | 22 |
| Off-grid >1kW | 19 |
| Grid-connected <=10kW | 10-12 |
| Grid-connected >10kW | 10 |

Table 3 provides cost comparable data; it is likely that there is better information regarding cost than was available in 2002, which at $6000/kW appears to be an underestimation.

**Table 3: Solar PV costs**

| Source | Capital cost ($/kW) | Fixed O&M costs ($/kW/year) | Variable O&M costs ($/MWh) | Fuel costs ($/MWh) | Network cost ($/kW) | Ancillary Services ($/MWh) |
|---|---|---|---|---|---|---|
| MMA (2009) | 7000 | --- | 5 | 0 | 50 | 8 |
| SEDA (2002) | 6000 | --- | 5 | --- | --- | --- |
| Access Economics (2009) | 7500 | 136 | 1.09 | --- | --- | --- |

[4] Cost of PV panels, does not include recurring costs such as the replacement of the inverter or batteries

Typical unit costs of grid-connected solar PV systems are in the range of 11-20c/kWh (Diesendorf, 2007), depending on the siting issues outlined.

### 6.3.4. BARRIERS & BENEFITS

The overwhelming barrier to PV technology is cost; without significant government subsidy or incentive, PV is not cost competitive with other renewable technologies, let alone current grid electricity prices. Another issue is that PV performance decreases when the cell temperature exceeds a threshold of 45°C, which means cooling systems are required in many Australian applications, further increasing the cost of PV.

- However, there are a number of significant benefits associated with PV. Diesendorf (2007) gives a good assessment:
- PV can be readily and quickly installed in a modular fashion on rooftops and integrated with building envelopes near electrical loads;
- PV is highly reliable and systems require very little maintenance, apart from the occasional cleaning and the replacement of inverters at the end of their lifetimes. Thus they are very simple technologies, although it should be noted that they are highly complex to manufacture.

### 6.3.5. SOLAR PV INDUSTRY AND COMMUNITY ENERGY APPLICATIONS

Since 2000, solar PV modules have taken the lead from wind power as the fastest growing energy supply technology in the world (Diesendorf, 2007). In 2004, Australian PV installations grew at a steady rate of 15% (Watt, 2005). Worldwide installed PV capacity exceeded 6GW in 2005 (Diesendorf, 2007).

PV systems are traditionally found in niche markets such as remote-area power supplies (Diesendorf, 2007). Off-grid power supply for industrial, agricultural and telecommunications applications was the largest PV market in Australia and accounted for 3.4MWpeak (MWp) in 2005, while off-grid residential systems account for 2.9MWp. In recent years, in part to do with the government PV rebate, the market in grid-connected solar systems has been growing quickly. Additionally, PV farms are being connected to many of Australia’s small diesel grid systems in remote towns (Watt, 2005).

The low carbon nature and modularity of PV systems makes them an ideal technology for community energy. Indeed many communities are already undertaking PV bulk purchasing schemes, often facilitated by local climate groups or organisations, while the Bega community group Clean Energy for Eternity is currently developing a community solar PV farm (CEFE, 2009). An additional benefit for the purpose of this research is that there is sufficient information available to model systems. Nevertheless, cost remains an issue.

## 6.4. COGENERATION AND TRIGENERATION

### 6.4.1. DESCRIPTION

Cogeneration technologies are defined as those that combine production of electrical power and useful thermal energy by the sequential use of a fuel or fuels (Turner, 2007). Forms of this thermal energy include hot exhaust gas, hot water, steam, and chilled water. Useful means that the energy is directed at fulfilling an existing need for heating or cooling (ibid). Usually, if a facility provides electricity, heating *and* cooling it is called a trigeneration facility as opposed to a cogeneration facility. Fuels used in cogeneration include coal, natural gas, petroleum-based products (diesel and fuel oils), solid biomass (e.g. bagasse), biofuels and biogas (Usher et al, 2008).

The literature describes four main electricity generating technologies used in cogeneration systems (Usher et al, 2008; Turner, 2007):

- Reciprocating gas engines, which convert energy contained in fuel into mechanical power which is used to turn a shaft in the engine, an attached generator converts the rotational motion into power;
- Combustion gas turbines where fuel is burnt in a combustion chamber with pressurised air to produce high pressure, high-velocity gas, this gas is then used to generate electricity in a turbine;
- Microturbines, which like larger gas turbines consist of a compressor, a combustion chamber, a one stage turbine and a generator; and
- Fuel cells, which use an electro-chemical reaction to create electrical current, similar to batteries however unlike batteries where the fuel is stored in a fuel cell the fuel is continually replenished.

Technologies installed to utilise the thermal energy produced by the technologies above include:

- Heat recovery equipment such as a convective heat exchanger or a “duct burner” (Turner, 2007);
- Absorption chillers, which use excess heat from a cogeneration facility to create chill water which can be used for cooling purposes; and
- Desiccants which produce dry air (Usher et al, 2008).

The final component of a cogeneration system is the heating and cooling and occasionally electricity networks. The scale of these networks can range from a large building to a district. The heating and cooling networks include a series of pumps and pipes that distribute to households or different parts of a facility heated or cooled water, air or steam produced by the different technologies described above. This water can then be used for:

- “Climate control purposes” i.e. space heating and cooling;

- Industrial processes; or
- Hot or cold water (not always suitable for potable use).

### 6.4.2. TECHNICAL CONSIDERATIONS

Technical factors to be considered when developing a cogeneration project include, siting considerations, heat end-use, technologies to use and their electrical and total efficiencies (Table 4), as well as the distribution network structure.

**Table 4: Technical features of cogeneration devices**

| Technology[5] | Reciprocating engines | Combustion turbines | Microturbines | Fuel Cells |
|---|---|---|---|---|
| Fuels* | Gasoline, natural gas, biogas and diesel fuel | Natural gas, oil or a combination of fuels | Natural gas, hydrogen, propane or diesel | Natural gas, biogas and petroleum products converted to hydrogen |
| Size* | 5kW-7MW + | 500kW-25M | 25-500kW | 1kW-10MW |
| Electrical Efficiency* | 25-45% | 25-40% | 20-30% | 25-60% |
| Total Efficiency** | 75-85% | 75-85% | 75-85% | 75-85% |

It is interesting to note that despite different electrical efficiencies, total efficiency of cogeneration plants is the same across all technologies, suggesting that the total efficiency has more to do with the heat use technologies. An additional technical considerations is the capacity factor of cogeneration, Glassmire et al (2009) suggest a maximum capacity factor of 95% and a typical capacity factor of 60%, while MMA (2007) uses a typical capacity factor of 70% for natural gas fuelled plants.

**Scale**

Table 4 gives the different power output scales of the different technologies, which range from very small 1kW fuel cells to medium sized 25MW combustion turbines. Although it is important to note that Table 4 is a review of small-scale cogeneration technologies and that technically coal fired power stations can have cogeneration functionality. The scales

[5] *Source: Usher et al, 2008
**Source: Alanne, K and Saari, A. 2004 in Turner, 2007

translate to space requirements of anything from part of the basement of an apartment block to large power stations.

**Siting considerations**

Cogeneration plants should be in easy distance to a fuel source and a heating and electricity load demand.

### 6.4.3. COST

The Renewable and Distributed Generation Working Group (RDGWG, 2006 in Usher et al, 2008), estimates the electricity generating costs for cogeneration plants in the range of 4-5c/kWh for large gas turbines to 6-7/kWh for small reciprocating gas engines. Although these costs compare favourably with grid electricity prices, the high capital costs and associated pay back periods represent a barrier to uptake (Usher et al, 2008). Table 5 gives the likely capital costs for different cogeneration technologies. They show that reciprocating engines and microturbines are essentially cost comparable although microturbines have lower maintenance costs. An additional variable is the cost of different fuels. It is important to note that Table 3 is US data; MMA (2007) suggests that the likely cost of cogeneration in Australia is $1553/kW capital cost, $3/MWh variable operating cost and $20/kW/year fixed costs for a residential system. MMA (2007) does not specify what cogeneration technology these costs relate to, but it would not be fuel cells as they are still in commercialization and thus very expensive.

**Table 5: Capital and maintenance costs for different cogeneration technologies (Turner, 2007)**

| Technology | Reciprocating engines | Microturbines | Fuel Cells |
|---|---|---|---|
| Investment Costs (US$/kW) | 800-1500 | 900-1500 | 2500-3500 |
| Maintenance Costs (USc/kW) | 1.2-2.0 | 0.5-1.5 | 1.0-3.0 |

### 6.4.4. BARRIERS AND BENEFITS

There are a number of barriers and benefits of cogeneration as an energy technology category, as well as barriers and benefits associated with specific technologies and fuels. Table 6 outlines the strengths and weaknesses of the four main cogeneration technologies.

Air emissions associated with cogeneration technologies, particularly reciprocating engines are a barrier that must be overcome. The typical air pollutants associated with cogeneration include:

- Oxides of nitrogen
- Carbon monoxide
- Oxides of sulphur
- Unburnt hydrocarbons
- Particulate matter (Usher et al, 2008)

**Table 6: Strengths and weaknesses of co-generation technologies (developed from Usher et al, 2008)**

| Technology | Weaknesses | Strengths |
|---|---|---|
| Reciprocating engines | High atmospheric emissions of $NO_x$, noise and frequent maintenance requirements | Low capital cost, good electrical efficiencies, fuel flexibility, high reliability, low natural gas pressure requirements and quick start up |
| Combustion turbines | Reduced efficiencies at part load, sensitivity to ambient conditions (temp and altitude), lower cost efficiency for smaller systems | High efficiency and low cost particularly in large systems, size range, proven reliability and availability, high power to weight ratio, ability to produce high pressure steam using exhaust heat |
| Microturbines | Low fuel to electricity efficiencies and loss of power output and efficiency with higher ambient temperature and elevations | Low $NO_x$ emissions, small number of moving parts, compact size, light weight, low emissions, ability to use waste fuels, long maintenance intervals |
| Fuel Cells | Very high cost | Quiet, zero $NO_x$, high electrical efficiencies different technologies have different strengths and weaknesses |

These are subject to regulation and often require additional technologies to bring emissions down to an acceptable level. Other limitations of cogeneration include:

- The water and space requirements for large cooling towers, needed by absorption chillers to shed large quantities of excess heat. Although alternative cooling systems, such as geothermal heat exchange, are a possible option (ibid);

- Capital cost and payback period;
- Lack of experience in Australia with cogeneration technology;
- The "lack of streamlined processes for approval and connection of cogeneration plants" (ibid).

The benefits of cogeneration include:

- Components and equipment are well developed and procedures to integrate these components into cogeneration systems are well established (Turner, 2007);
- When fuelled by natural gas or renewable fuels, cogeneration can deliver electricity with much lower emissions intensity than the grid (Usher et al, 2008), for example Glassmire et al (2009) assign cogeneration an emissions factor of 0.3tonnes $CO_2e$/MWh;
- The use of waste heat means that overall efficiency of energy conversion is greatly increased (ibid); and
- Cogeneration also offers the potential to reduce peak electrical demand, thereby reducing the need for network augmentation (ibid).

In general, cogeneration plants are quite complex and thus require operations and maintenance staff. However, this staffing requirement can be seen as a benefit, as it can lead to new skilled jobs in the community.

#### 6.4.5. COGENERATION INDUSTRY AND COMMUNITY ENERGY APPLICATIONS

Cogeneration is used extensively around the world, particularly in Northern Europe where there are large heating loads. For example, in Denmark district heating networks supply 60% of the heated floor area, with cogeneration supplying 50% of the heat (URBED, 2003). In Australia, a number of companies exist that undertake co-generation projects, for example Grid X, an energy services company.

Cogeneration is a technology that using either natural gas or biomass fuels would be appropriate as the basis of a community energy project in Australia. This is because it fulfils the decarbonising and distributing requirements for community energy application. Also internationally, cogeneration plants have been used by energy services companies and developed by community organisations. The most widely known example is Woking in the UK, which has a number of different cogeneration facilities using different technologies (absorption chillers, fuel cells, private electricity wire) (Thompson, 2007). In Australia, City of Sydney, Moreland and Moonee Valley Councils are all planning cogeneration facilities.

## 6.5. BIOENERGY

### 6.5.1. DESCRIPTION

Bioenergy is the oldest form of energy used by humans; since prehistoric times humans have burnt wood to generate heat but in modern times, many additional processes have been developed to convert biomass resources into energy useful for humans. Bioenergy is defined as the useful energy produced from biomass (Diesendorf, 2007; CEC, 2008). It converts the solar energy that is stored in biomass as chemical energy into thermal and electrical energy. Biomass sources are renewable organic materials (Diesendorf, 2009) and fall generally into the following categories - agricultural related wastes, energy crops, landfill gas, sewage gas, sugarcane, urban biomass (including urban timber wastes), and wood related wastes (CEC, 2008).

The field of bioenergy technologies is diverse and comprises three fundamental components - purpose (energy end use), biomass resource and conversion process. Figure 16 outlines some of the diversity of bioenergy technologies, by mapping possible options and interactions between these components.

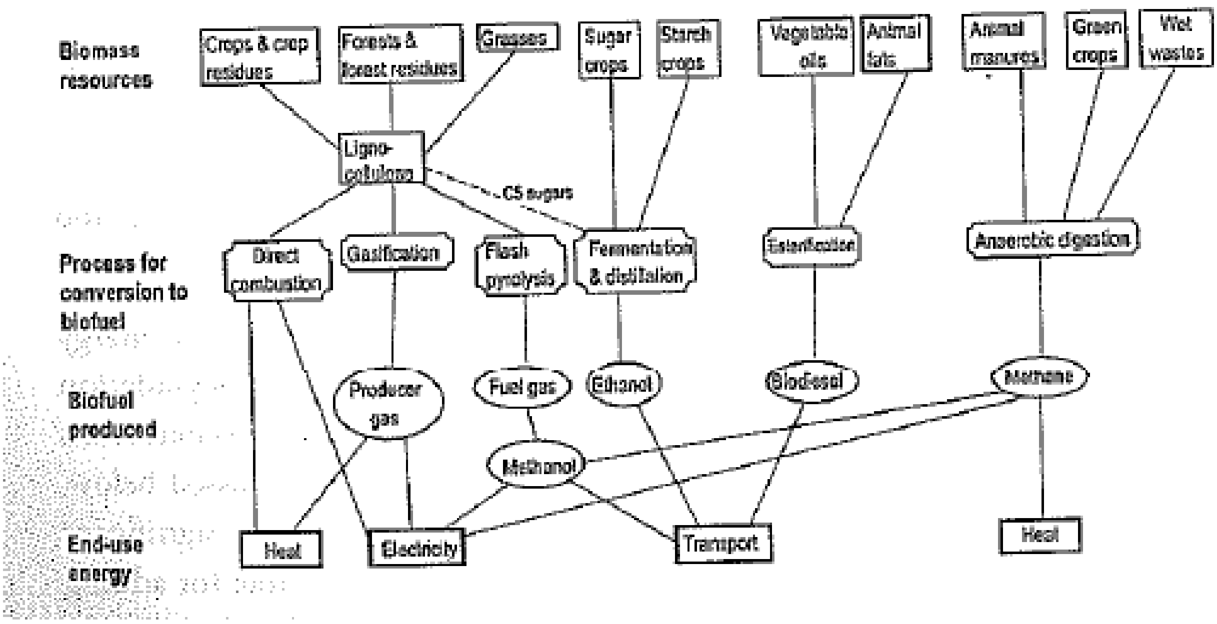



**Figure 15: Some pathways for converting biomass into useful bioenergy (Diesendorf, 2007)**

Within this thesis it is not possible to discuss all options detailed in Figure 15. However, this thesis is concerned with stationary community energy projects, thus, by definition, this excludes those bioenergy options that have transport as its end use (these processes typically involve converting biomass into liquid fuels such as methanol and will not be considered here). Other options beyond the scope of this thesis include landfill and sewage gas biomass resources as most are currently utilized by the sewage and landfill operators and thus not relevant to community energy projects.

### 6.5.2. TECHNICAL CONSIDERATIONS

In the bioenergy literature reviewed there were three main conversion processes used to generate heat and electricity – thermal gasification, direct combustion and anaerobic digestion (Diesendorf, 2007; CEC, 2008; Stucley et al, 2004; Brown, 2007).

**Thermal gasification**

Thermal gasification involves the conversion of solid fuels into flammable gas mixtures, by heating it in limited oxygen (Brown, 2007; CEC, 2007). The gas can then be used in gas turbines, internal combustion engines or fuel cells. To generate the highest gas yield, the process requires a fibrous plant material feedstock, which has high volatile content and is highly carbonaceous. As such, wood and crop wastes or dedicated crops are typically used. Typical efficiencies of this process range from 90% at very high temperatures, to 50-60% at low temperatures. However, generating high temperatures either requires some of the feedstock to be combusted or an external heat source. Thus the optimum temperature of the process becomes a question of economics based on the trade off between fuel requirement and efficiency.

**Direct combustion**

Direct combustion technologies are the most proven and commercially viable of all the biomass conversion technologies (CEC, 2008) as they are also used to convert coal into electricity. Biomass fuels, typically wood, agricultural residue, biogas or wood pellets (Diesendorf, 2007; CEC, 2008) are combusted to generate steam, which in turn drives a Stirling engine or Rankin steam power cycle (Brown, 2007). Direct combustion is not as efficient as thermal gasification, although efficiencies of over 80% are possible if a cogeneration application is applied (using both heat and electricity generated) (CEC, 2008).

**Anaerobic digestion**

Anaerobic digestion is a bio-chemical energy conversion process that converts half the biomass feedstock into biogas and the other half into organic slurry which can be used as fertilizer (CEC, 2008). The biogas can then be used for direct combustion or in gas turbines. Feedstocks for anaerobic digestion are usually wet wastes such as livestock manure, green wastes such as crop residue and municipal solid waste (ibid; Diesendorf, 2007). This process is proven commercially in Australia and around the world; however it has lower efficiencies than the other two processes considered.

**Energy generation**

The modelling techniques available to calculate energy output from a biomass plant depends on the energy content of the fuel used the efficiency of the conversion process and the capacity factor of the plant. Access Economics (2008) suggests that the typical capacity factor of bioenergy plants is 80%, while Stucley et al (2004) and RIRDC (2008) detail the energy content of different fuels. The specific energy content and conversion efficiency assumptions used in CEDAT are discussed in Section 7.2.3.

**Scale**

Bioenergy conversion technologies are technically feasible at scales ranging from hundreds of kilowatts to hundreds of megawatts, although they are generally smaller than coal fired power stations (Diesendorf, 2007). The main factor when scaling a bioenergy facility is resource availability, which varies depending on the location (Diesendorf, 2007). There are natural limits to the amount of biomass that is available to fuel bioenergy plants, these limits are compounded by economic, environmental and social constraints discussed in the sections below. The literature indicates typical size ranges for different bioenergy plants. Ragwitz et al (2009) suggest in Europe that agricultural biogas plants range from 0.1-0.5MWe[6] and direct combustion biomass plants range from 1-25MWe. However, in Australia, MMA (2007) indicate a typical bioenergy plant size of 30MWe.

**Capacity Factor**

Biomass has the potential to provide baseload power supply, which is reflected in its capacity factor. Biomass conversion technology is essentially the same as that used in fossil fuel power plant, as such the technical capacity factor is similar. However, the availability of biomass feedstock could be more variable, resulting in a slightly lower capacity factor. In the literature biomass capacity factors range from 70% (MMA and the Climate Institute, 2008) to 85% (Glassmire et al, 2009), while Access Economics (2008) uses 80%.

### 6.5.3. COST

Predominantly the literature which describes the cost of bioenergy is different from the literature detailing the technical processes involved. As such, most costs do not relate specifically to one technology, they are instead an average of gasification and direct combustion technologies as the most widely used technologies. However, different fuel costs are specified based on different biomass resources. RIRDC (2008), suggests fuel costs, including harvest and transport range from \$0/tonne for bagasse (sugarcane residue) to \$65/tonne for dedicated energy crops, while Stucley et al (2004) assumes an average of \$30/wet tonne of biomass in calculations.

The lifespan of a bioenergy plant is typically 15 years (MMA, 2007). Capital costs associated with the complex energy conversion technologies are considered high (Diesendorf, 2007;

[6] MWe is the nameplate power of a plant, according to its maximum electrical power output. When discussing cogeneration applications, it is important to specify between thermal power and electrical power potential.

Stucley, 2004; CEC, 2008; RIRDC, 2008). Table 7 outlines the cost comparable data available, while Table 8 outlines how costs change associated with different size plants.

Beyond capital cost, it is difficult to compare the cost information in Table 7 due to the range of different variables used. MMA (2009) have the highest capital cost and SEDA (2002) the lowest, indicating that either the technology has become more expensive with time or that the increase in size of the bioenergy industry means that costs in the literature are now more accurate.

**Table 7: Bioenergy Costs**

| Source | Plant size (MW) | Capital cost ($/kW) | Fixed O&M costs ($/kW/year) | Variable O&M costs ($/MWh) | Fuel costs ($/MWh) | Network cost ($/kW) | Ancillary Services ($/MWh) |
|---|---|---|---|---|---|---|---|
| MMA (2009) | <2 | 4000 | --- | 8 | 15 | 50 | 0 |
| SEDA (2002) | --- | 2200 | --- | 10 | --- | --- | --- |
| Access Economics (2009) | --- | 3000 | 84 | 6.03 | --- | --- | --- |
| MMA (2007) | 30 | 2318 | 50 | 4 | 15 | 100 | 0 |

Table 8 indicates that there are significant economies of scale to be captured as plant size increases, in terms of both capital and operation and maintenance costs. However, it is questionable as to whether the true cost of fuel is accounted for in the 30MW plant calculations in Table 8. This is because providing the large biomass feedstock load required for larger plants increases the cost of transporting the biomass to the plant (Diesendorf, 2007), making larger plants potentially more uneconomical. Unit costs for biomass plants are quoted as ranging from 6c/kWh for a large plant with a bagasse feedstock (RIRDC, 2008) to 20c/kWh for a smaller plant (Stucley et al, 2004).

**Table 8: Bioenergy cost variation with scale (Stucley et al, 2004)**

| | 1 MW | 5 MW | 30 MW |
|---|---|---|---|
| Feed requirement (green kt/yr) | 13.7 | 91.2 | 429.0 |
| Capital Cost (M$/MW) | $5.3 | $2.5 | $1.58 |
| O&M Cost (M$/MW/yr) | $0.3 | $0.16 | $0.10 |

### 6.5.4. BARRIERS & BENEFITS

Bioenergy technologies are contentious; if designed properly they can have many social, environmental and economic benefits, however if designed badly they can do more harm than good. Potential benefits include, providing a market for local produce such as agricultural waste (Walker, 2008) and creating new jobs in rural areas (RIRDC, 2008; Diesendorf, 2007). Additional benefits and limitations relate to the biomass resource used, specifically there is much debate globally as to the sustainability of dedicated energy crops. Palm oil and sugar cane plantations in Indonesia and Brazil respectively, have caused landclearing of old-growth forests, displacing communities, decreasing biodiversity, removing natural carbon stores and interrupting water and nutrient cycles. Similar impacts on Australia's native forest ecosystems are possible, The Wilderness Society (2009) warns if bioenergy policy is not managed correctly. Additionally, dedicated energy crops compete for land with food crops, which can lead to food shortages and/or an increase in food prices, for humans and livestock. Conversely, if managed well multi-purpose energy crops such as oil mallee could have additional benefits such as reducing dryland salinity in Australia (RIRDC, 2008; Diesendorf, 2009).

Another issue is that growing, harvesting and transport of biomass involves the use of fossil fuels, so while biomass is a renewable energy source, and is less emissions intensive than coal based electricity, it is not *necessarily* a carbon neutral technology. Bioenergy generally reduces air pollution associated with coal fired power stations, although direct combustion technologies do produce some particulates.

Based on this assessment of limitations and benefits of bioenergy technologies it is clear that the most sustainable biomass resource for bioenergy purposes is agricultural residues such as crop stubble. This is because it doesn't compete with other land uses or result in an increase in fuel or water use (Diesendorf, 2007), however this does not consider the overall sustainability of modern farming practices as it is beyond the scope of this research. Sustainable agricultural biomass *can* be considered carbon neutral, if the biomass used for energy is replaced at the same rate. However, crop residue is used to protect the soil surface and conserve nutrients (ibid). As such, to be sustainable not all residue should be harvested for energy purposes and the ash produced, should be returned to the land where the biomass was grown, to maintain the nutrient levels (ibid).

Similar to cogeneration technology bioenergy systems can be quite complex to maintain, however the need for operational staff can generate additionally skilled employment in the community.

### 6.5.5. BIOENERGY INDUSTRY AND COMMUNITY ENERGY APPLICATIONS

In Australia, bioenergy contributes only 0.9% to Australia's current electricity generation (CEC, 2009), although accounts for 4.3% of the primary energy supply, which also considers heat and transport applications (IEA, 2006 in Diesendorf, 2007). However, globally bioenergy contributes an average of 10.6% of primary energy supply (ibid) and in Europe between 4 to 14% of total electricity generation (CEC, 2009). These statistics indicate that it is likely that much of the world still relies on traditional bioenergy systems (for example wood fires), but that there is also a large modern bioenergy industry. A recent bioenergy resource appraisal and roadmap (CEC, 2009) suggests that Australia should aim to generate 4% of its electricity from bioenergy.

Bioenergy systems are generally well suited to community applications, due to their scalability, the added benefits they bring to a community and that they are a low carbon technology option. Internationally, a number of community bioenergy projects already exist, for example, groups of Austrian farmers have formed co-operatives to invest in modern automated wood waste pellet heating plants (URBED, 2003). While in Australia, a 3MW biomass cogeneration plant is proposed for Western Victoria (Hepburn Wind, 2009).

## 6.6. SUMMARY

Based on this review it is clear that there are five appropriate technology options that communities should consider that also have sufficiently simple modelling information that could be incorporated into a community energy tool. They are:

- Solar PV;
- Wind – using utility scale turbines;
- Mini-wind, using 10kW sized turbines;
- Cogeneration plants fuelled by natural gas; and
- Agricultural biomass.

Table 9 provides a summary and comparison of the key technical and economic variables associated with each option. Where possible MMA (2009) cost data has been used, as it specifically assumes community energy application and is the most complete data set, thus enabling more reliable comparison across the technology options.

From this table it is clear that solar PV is the most capital intensive technology option, followed by agricultural biomass, while cogeneration is the cheapest option. Cogeneration is also the most technically consistently available technology with a maximum capacity factor of 85%, while solar PV and wind are the most intermittent technologies with low capacity factors of 20% and 30% respectively. That is not to say that solar PV is not reliable, just that it only produces electricity during daylight hours.

This data and technical review provides the basis for the development of the community energy tool, discussed in the following chapter.

### Table 9: Technology costs and performance assumptions

| Technology | Unit Size [MW] | Max Size[7] [MW] | Lifetime [years] | Capital cost [$M/MW] | Fixed O&M costs [$M/MW/y] | Variable Costs - Fuel and Incremental O&M [$/MWh] | Transmission Costs[8] [$/kW] | CF[9] [%] |
|---|---|---|---|---|---|---|---|---|
| **Wind** | **0.5-2.5** | **30** | **25** (MMA, 2007) | **2.5** (MMA, 2009) | **0** (MMA, 2009) | **15** (MMA, 2009) | **50** (MMA, 2009) | **35%** (MMA, 2007) |
| **Mini Wind** | **0.01** | **0.5** | **15** (NREL, 2005) | **3.7** (NREL, 2005) | **0.006** (NREL, 2005) | **0** (NREL, 2005) | **50** (MMA, 2009) | **35%** |
| **Solar PV** | **0.001** | **30** | **25** (MMA, 2007) | **7** (MMA, 2009, Sydney Energy Co-op, 2009) | **0** (MMA, 2009) | **13** (MMA, 2009) | **50** (MMA, 2009) | **20%** (MMA and the Climate Institute, 2008) |
| **Cogeneration** | **0.01** (Usher et al, 2007) | **30** | **25** (Glassmire et al, 2009) | **1.55** (MMA, 2007) | **0** (MMA, 2007) | **22.2**[10] (MMA, 2007, ACIL Tasman, 2009 and Alaan and Saari, 2004) | **50** (MMA, 2009) | **85%**[11] |
| **Agricultural biomass** | **0.1** (Ragwitz et al, 2009) | **30** | **25** (MMA, 2007) | **4** (MMA, 2009 and RIRDC, 2008) | **0** (MMA, 2009) | **45.5**[12] (MMA, 2009, Stucley et al, 2004 and RIRDC, 2008) | **50** (MMA, 2009) | **80%** (Access Economics, 2008) |

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[7] Max size is caped at 30MW, as that is the maximum size plant that can feed into the distribution network. However, mini-wind is capped at the minimum size of large wind.
[8] Unit transmission costs are assumed to be technology neutral, thus MMA, 2009 data is applied to all options
[9] Capacity factors are an estimate and included in this table for comparison. PV, wind and mini-wind capacity factors are site dependant and thus are not used in CEDAT modeling.
[10] Variable cost from MMA and the Climate Institute (2008). Fuel cost assumed a gas cost of $4/GJ (based on ACIL Tasman, 2009 gas costs), assume cogeneration has a total efficiency of 75% (Alaan and Saari, 2004 in Turner, 2007)
[11] A middle value is assumed from those in the literature, but above Agricultural Biomass.
[12] Variable cost from MMA (2009). Fuel costs assume $30/wet tonne (Stucley et al, 2004) and a conversion factor of 0.8MWh/wet tonne (RIRDC, 2008)

# 7. DEVELOPMENT OF THE COMMUNITY ENERGY DECISION ASSISTANCE TOOL (CEDAT)

This research to date has identified that a simple to use energy modelling tool that incorporates a MCDA process with five technology options – wind, mini-wind, solar PV, agricultural biomass and cogeneration could be one method for addressing the technical knowledge constraints that community energy projects face. As such, the methodology for this research will be the creation and trial of such a stand-alone decision-support tool that could in the future be further developed into a web-based decision-support tool. The name of the tool developed is the *Community Energy Decision Assistance Tool* (CEDAT).

CEDAT uses an MS Excel platform to provide a framework for users to better understand low carbon technology options suitable for a specific community and to target further investigation. It will do this by providing users (i.e. community groups) with a starting point. Users are guided through a series of questions regarding aims of the project and information related to the geographical location and expected energy use of the community. CEDAT then provides preliminary economic, environmental and technical information for each of the technologies, and guidance on sourcing further information for subsequent investigation. It is important to note that CEDAT is a decision-support tool that provides a preliminary assessment of suitable energy options, and will not eliminate the need for outside technical expertise, particularly in the feasibility study and detailed assessment stage.

**Target audience**

The target audience for CEDAT is community groups/organisations and specific community energy proponents that are in the initial stages of developing a community energy project. In the development of CEDAT, significant thought has been given to the specific needs and knowledge of potential CEDAT users. It is envisaged that the users of CEDAT would range from lay people with little to no technical knowledge of sustainable energy systems, to those with experience in the energy industry who are looking to facilitate the involvement of a wider group of interested people. Thus, CEDAT faces the same challenge noted in the ESAT Manual (SAP, 2008) – the need strike a balance between "specificity and simplicity". CEDAT will have to be sufficiently specific so that when utilized by energy professionals its results are useful for their needs, while also being sufficiently simple so that people with little technical energy knowledge are able to understand and find the necessary input information. As such, data accessibility was a key considered in the development of CEDAT, as it was thought that many CEDAT users were unlikely to have access to extensive context specific data

**Outputs**

To fulfil its purpose, CEDAT has three essential outputs:

- Information about the likely technical arrangements of each technology option based on community specific inputs for example size (MW);
- Environmental, economic and socio-technical indicators for each option which form the basis of the MCDA process; and
- A weighted total score for each technology option based on the MCDA.

The processes modelled in CEDAT which lead to these three outputs are described in the remainder of this chapter.

## 7.1. ENERGY USE MODEL

In order to produce all of the outputs detailed above, it was necessary to model community energy use based on community specific information. An 'energy use model' usually forms the basis for any location specific energy modelling process, be it at a national, regional, community or household scale. This section discusses what energy parameters are considered in CEDAT and why and then outlines CEDAT's energy use modelling process.

The two most important parameters for modelling both supply and demand of electricity are typically total energy and peak load also known as power. The power variable represents the maximum amount of useful energy (usually electricity) that is ever needed by a community or produced by a technology at one time; it is measured in kilowatts (kW) or megawatts (MW). The total energy needed/generated variable is a measurement of the amount of energy produced or required over a specified time period usually a day or a year; it is usually measured in kilowatt hours per day (kWh/day) or megawatt hours per year (MWh/y)

One of the major challenges for energy planning at any scale is matching both supply and demand of these two parameters (power and total energy). While theoretically it is possible to closely match supply and demand energy loads at a community scale as discussed in Section 3, in practice the process is complex and challenging. To completely match supply and demand of power and energy use in a community normally requires energy storage technologies such as batteries, which adds significantly to the cost of an energy system. To model this process requires energy load curves which at a community scale are hard to find or create. An alternative to batteries is to match energy generation technologies to specific energy loads and vice versa. For example solar lights for street lighting or solar water pumps that only pump water when the energy is available. Although at a community scale this can be done, it is extremely complex and thus very difficult to design as part of a generic model. There are particular institutional arrangements that would be able to undertake the complex planning process of matching demand and supply loads. Specifically:

- Energy service companies which are likely to have the technical knowhow or financial resources to design such a complex system;

- Eco-villages that are starting from scratch,  thus the community can be designed intentionally; and
- Small remote communities that already function this way.

However, community groups that wish to develop a community energy project for an existing grid connected community matching loads is a complex process and for the scope of this thesis is too complex.

Of the two parameters – energy and power, power is the most difficult to determine. Further, at a community scale knowing power requirements is only necessary for two main purposes:

1. If the community is trying to be completely energy self-sufficient and thus independent of the electricity grid; or
2. To determine the precise cost of connecting a technology to the electricity grid.

However, given the complexity associated with a community becoming energy self-sufficient and that a tool to support this process already exists (HOMER), for this research it will be assumed that communities will remain grid connected.

By making the assumption that the community remains grid connected this means that the power variable is less important as communities are able to export excess energy and import energy as needed.  This assumption also reduces the requirement for storage technologies, as the grid acts as a large battery.  As for the concern about network connection cost, CEDAT only gives a likely cost of project and will not be sufficiently accurate for this issue to significantly impact the outcome.  Although some network cost is considered as shown in Section 6.6, Table 9.  Assuming the community remains grid connection, best suits projects with co-operative type arrangements whose purpose is to meet all or a proportion of the communities *average* energy needs.  An additional simplification associated with this assumption is there is little need to consider temporal variation of demand as these variations relate more closely to peak energy use, not total energy use.  As such, annual energy use is the primary basis of the energy use model and thus one of the fixed variables around which size of technology and thus cost and emissions abatement are optimised.

To calculate annual energy use of the specific community, users are given three options (as seen in Figure 16):

1. Specify the population of the community;
2. Specify the population of the community, average household daily energy use and average number of people per household; or
3. Specify the community's annual energy usage.

Progressing down the list, options become increasingly hard to input find data, but increasingly accurate.  Annual community energy use is directly calculated (Fig Y) in the second two options, while the first option, and requires two assumptions to be programmed into CEDAT, specifically:

1. Number of people per household - 2.6 is assumed based on ABS statistics (ABS, 2004); and
2. Average household energy use.

It was a challenge to find average Australian household or community energy use data. There are statistics on the proportion of energy or emissions that the residential sector accounts for and many household ecological footprint and emissions calculators available. However, at a community scale, there is little data available, which reflects an observation made by Holmes a'Courte (2009) - that most energy policies and tools focus either on the economy wide or individual scale projects. Nevertheless, average household energy use has been calculated in CEDAT, using data from the *Energy Use in the Australian Residential Sector: 1986-2020 Report* (DEWHA, 2008). Specifically, Equation 2 was applied, the results of which are shown in Table 10.

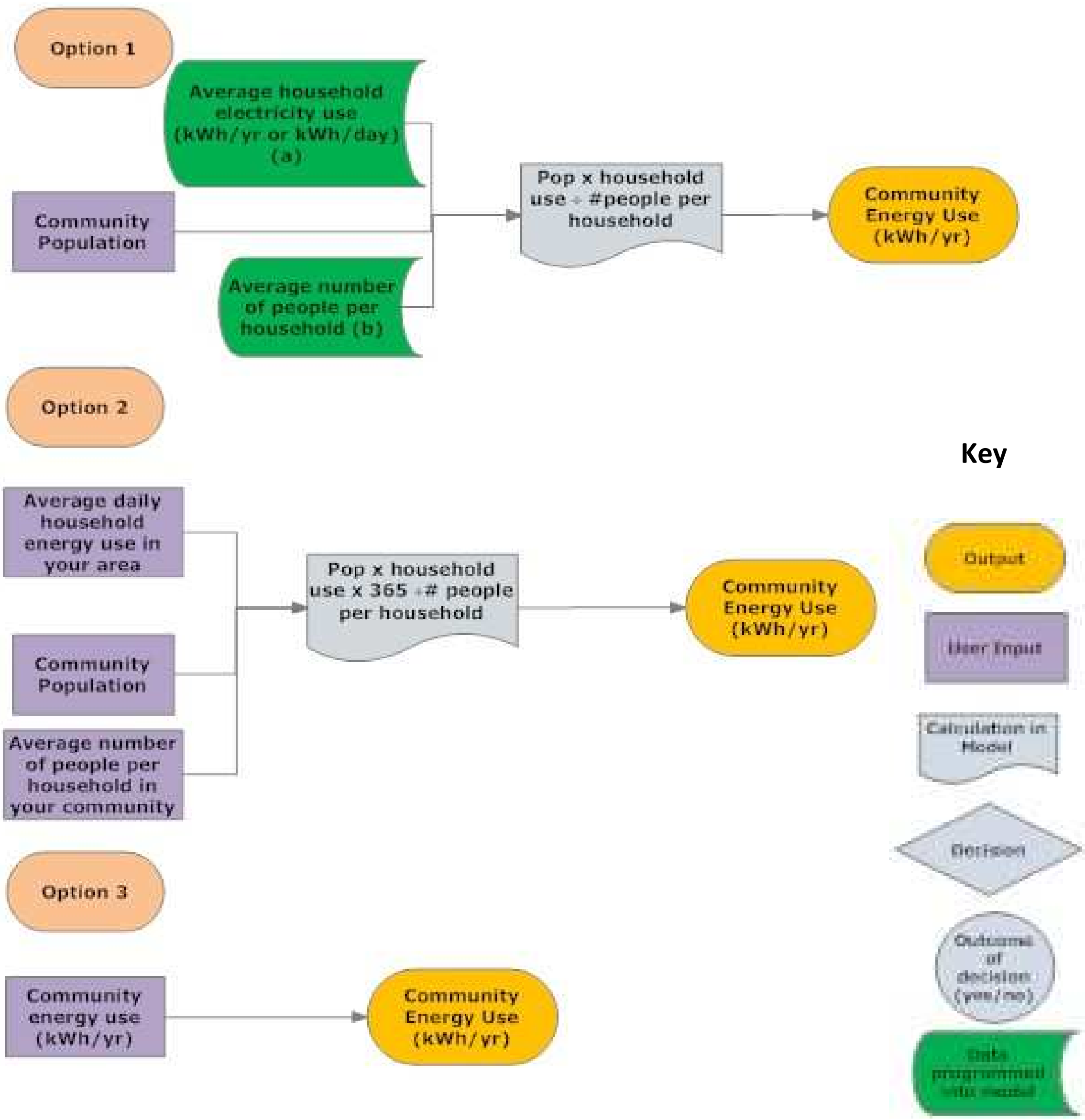


Figure 16: Energy use modelling options flowchart

**Equation 2**

$$\text{Average household energy use} = \frac{\text{Total energy use in the residential sector}}{\text{Total number of occupied households}}$$

State based data is used to ensure that there is some locational variation; a consequence of this is that specifying a state must be a user input field in CEDAT. Also, 2005 data is used because it is the last year in which the residential energy use and number of occupied household's statistics are based on observed data (DEWHA, 2008).

**Table 10: Average household daily energy use per state (DEWHA, 2008)**

| State | Average household energy use (kWh/day) |
|---|---|
| ACT | 54.15 |
| New South Wales | 30.32 |
| Northern Territory | 25.39 |
| Queensland | 22.99 |
| South Australia | 33.69 |
| Tasmania | 62.90 |
| Victoria | 58.32 |
| West Australia | 30.41 |

There are a number of limitations with this approach to calculating community energy use including:

- Average household energy use figures do not incorporate any significant improvements in household energy efficiency;
- Average household energy use statistics seem very high; and
- Total residential energy use statistic incorporates household energy consumption from electricity, gas, wood and LPG, thus the average does not specify for differences between houses that use gas and electricity and houses that just use electricity. This is potentially significant as gas appliances such as gas stoves are more efficient and thus make households less energy intensive.

Despite these limitations, this energy use modelling option is important to include as it ensures that CEDAT is easily accessible for users, with minimal access to data.

The first two energy use modelling options detailed in Figure 16 assume that communities only have residential energy needs. In reality communities include commercial enterprises and some industrial processes. Industrial processes can access capital and are often well suited to specific energy technologies, for example capture and use of methane in Waste Water Treatment Plants. As such, industrial energy needs are not considered in CEDAT. However, given that small businesses are important parts of a community and often do not have the ability to access capital required for an energy generation project on their own, there is an option in the CEDAT User Interface to incorporate commercial energy loads. If users specify residential *and* commercial energy use, community energy use is calculated based on the process outlined in Figure 17.

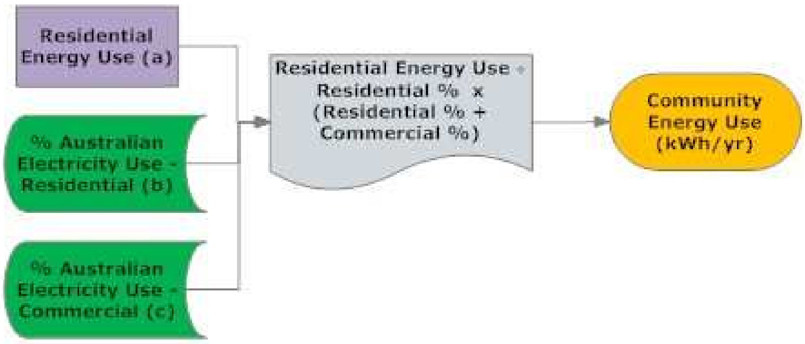


**Figure 17: Modelling commercial community energy use flowchart**

This process may overestimate energy consumption; however it provides a simple mechanism for incorporating commercial enterprises' energy use, if the user is so inclined.

## 7.2. MODELLING ENERGY GENERATION FOR EACH TECHNOLOGY OPTION

In order to produce all of the desired outputs detailed in the beginning of this chapter, it was necessary to model energy generating potential of each technology option, based on community specific information.

To successfully model the solar and wind technology options included in CEDAT a source of reliable climate data was necessary. However, one of the major constraints facing renewable energy technologies is the lack of adequate energy resource data (Kaye, 2008). Most data sets are costly, not available to the public or only available in a limited number of libraries. However, *The Australian Renewable Energy Atlas* (DEWHA, 2009) is an online publicly accessible resource and thus an ideal dataset for CEDAT (see Figure 18). The existence of this Atlas removes the need for CEDAT to include an interactive map similar to the one found in ESAT. Instead, when using CEDAT, people are directed to input solar and wind information for their community from *The Australian Renewable Energy Atlas* (Figure 19). One limitation of relying on *Australian Renewable Energy Atlas* which has set parameters is that it constrains the wind and solar modelling methodologies.

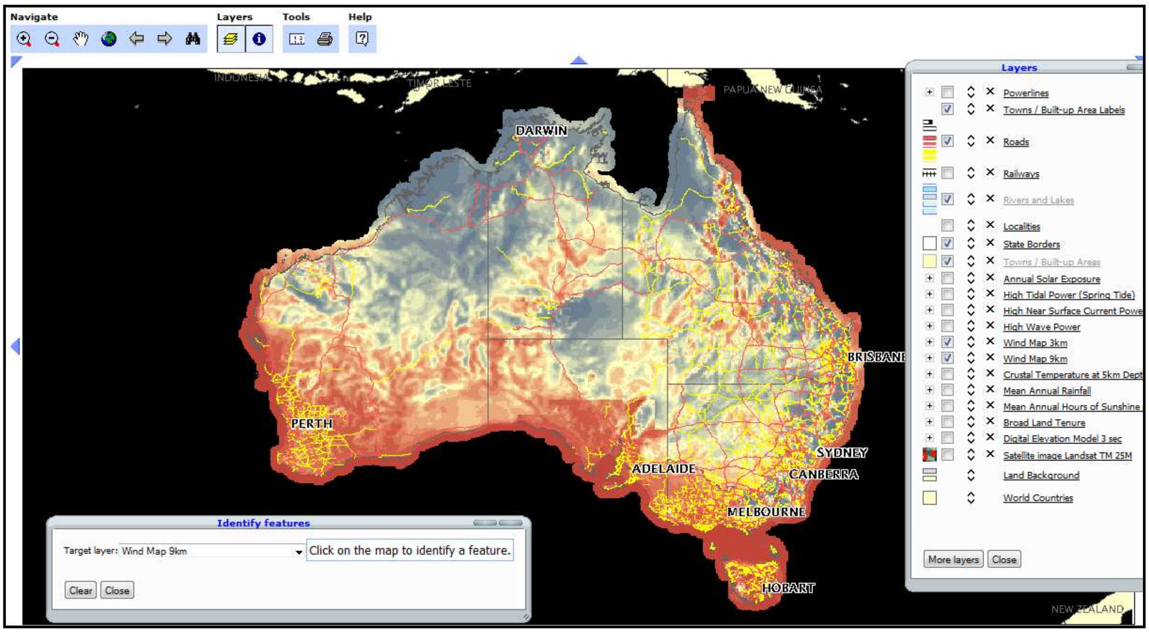


Figure 18: Australian Renewable Energy Atlas (DEWHA, 2009)

For each technology option in CEDAT a flowchart was developed to determine how to best incorporate the technology into CEDAT. These flowcharts utilize simple technology specific rules of thumb found in the literature. The process for determining which rule of thumb or methodology to use for each technology was iterative and based on available input data, range of potential methodologies and two criteria. The criteria for incorporating a specific rule of thumb was that they did not require too much user defined information, and would still provide reasonably accurate information that differentiated the viability of a technology based on the location of the community.

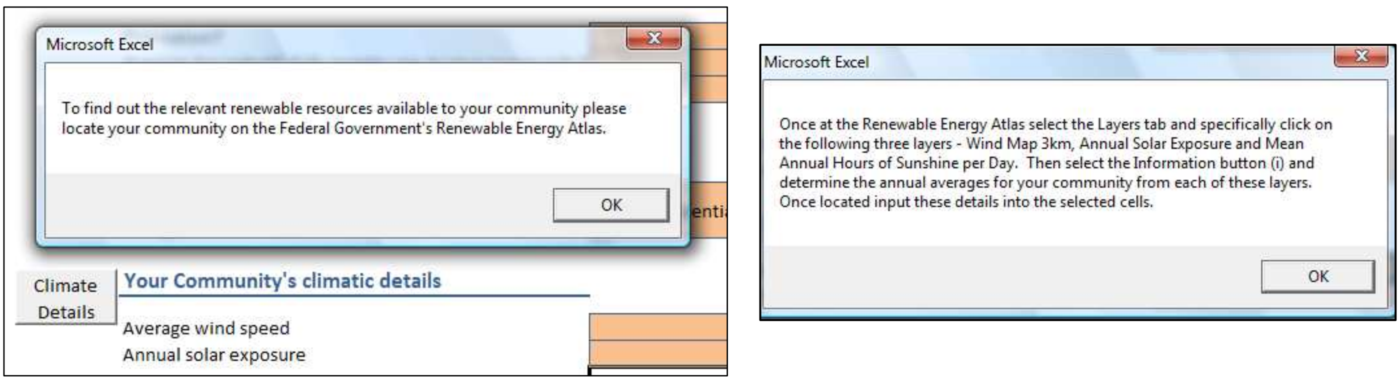


Figure 19: CEDAT climate data input instructions

### 7.2.1. WIND AND MINI-WIND

Modelling the wind and mini-wind options built on information determined in the technical review and energy use modelling sections. These specified the key user defined inputs for wind technologies as wind velocity, land availability and community energy use. The desired outputs of this modelling were also known – energy use (MWh/yr), size of project (MW) and number of turbines. Thus, the unknown component was the wind energy modelling method. There are multiple wind modelling methods available, of which three are considered here.

**Method A – The Wind Engineering Approach**

The wind engineering approach involves applying Equation 3 to an 8760 hour dataset of wind velocities. Extrapolating an 8760 hour data set typically requires monthly wind speed averages and a Weibull k parameter, which is a measurement of the variability of the wind speed. Additional parameters considered include turbine efficiency, cut in and out speeds and wind shear associated with hub height and ground cover roughness.

**Equation 3**

$$P= 1/2\ k\ C_p\ \rho\ A\ V^3$$

Where:

P = Power output, kilowatts

$C_p$ = Maximum power coefficient, ranging from 0.25 to 0.45, dimensionless (theoretical maximum = 0.59)

ρ = Air density, $kg/m^3$

A = Rotor swept area, $m^2$

V = Wind speed, m/s

k = A constant to yield power in kilowatts

**Method B – NREL Estimation Approach**

The NREL estimation approach is based on Equation 4, which NREL (2005) recommends producing a preliminary estimate of the energy generation of small wind turbines. This approach is notably less accurate than a wind engineering approach as it does not consider wind variability, turbine efficiency and changes in density based on hub height.

**Equation 4**

$$AEO = 1.606\ D^2\ V^3$$

Where:

AEO = Annual energy output, kWh/year

D = Rotor diameter, m

V = Annual average wind speed, m/s

**Method C – Industry Data Approach**

The third approach considered uses wind industry data to calculate energy generation. Specifically, annual specific yields (kWh/m2/yr) for different average wind speed (Table 11) are applied to wind turbines of different sizes and thus swept area (Table 12). This approach takes into account air density and conversion efficiency of wind turbines at different speeds. It involves excel array operations to match energy produced with energy use, thereby determining the most appropriate configuration for the wind project in terms of the turbine size and number.

**Table 11: Estimated Annual Specific Yield at Hub Height Average Wind Speed (Gipe, 2008)**

| Average annual wind speed (m/s) | Air Density (W/m2) | Power Conversion Efficiency | Total Yield (kWh/m2/yr) |
|---|---|---|---|
| 4.0 | 75 | 0.350 | 230 |
| 4.5 | 107 | 0.360 | 340 |
| 5.0 | 146 | 0.370 | 470 |
| 5.5 | 195 | 0.360 | 610 |
| 6.0 | 253 | 0.350 | 770 |
| 6.1 | 266 | 0.346 | 800 |
| 6.2 | 279 | 0.343 | 840 |
| 6.3 | 293 | 0.340 | 870 |
| 6.4 | 307 | 0.335 | 900 |
| 6.5 | 321 | 0.330 | 930 |
| 6.6 | 336 | 0.326 | 960 |
| 6.7 | 352 | 0.323 | 1,000 |
| 6.8 | 368 | 0.320 | 1,030 |
| 6.9 | 384 | 0.315 | 1,060 |
| 7.0 | 401 | 0.310 | 1,090 |
| 7.1 | 419 | 0.305 | 1,120 |
| 7.2 | 437 | 0.300 | 1,150 |
| 7.3 | 455 | 0.295 | 1,180 |
| 7.4 | 474 | 0.290 | 1,200 |
| 7.5 | 494 | 0.285 | 1,230 |
| 8 | 599 | 0.260 | 1,360 |
| 8.5 | 718 | 0.235 | 1,480 |
| 9 | 853 | 0.210 | 1,570 |

Of the three methods considered, Method A requires inputs unavailable to the average CEDAT user. This is because the wind speed input is constrained by data available in the Renewable Energy Atlas, specifically annual average wind speed (m/s) and extrapolating an 8760 hour dataset of wind velocities from a single average annual wind speed data point is complex and unreliable. As such, Method A is not considered further.

To determine, which of the remaining methods should be used for large scale wind they were tested against known wind modelling data for the Hepburn Community Wind Farm (Hepburn Wind, 2009). The Hepburn Community Wind Farm will include two 2MW turbines and the site has an annual average wind speed of 7.7m/s. The results of this test are given in Table 13.

**Table 12: Swept area for different turbine sizes (Kaye, 2008)**

| Turbine size (kW) | Rotor Diameter (m) | Swept Area ($m^2$) |
|---|---|---|
| 2500 | 80 | 5027 |
| 2000 | 72 | 4072 |
| 1500 | 64 | 3217 |
| 1000 | 54 | 2290 |
| 750 | 48 | 1810 |
| 600 | 44 | 1521 |
| 500 | 40 | 1257 |

This test indicates that both Method B and C underestimate the energy generation potential of large scale wind. However, Method C has a smaller margin of error than Method B, 18% as opposed to 38%. As such, Method C will be used to model the Wind option in CEDAT. Figure 20 is a detailed flowchart outlining exactly how the wind option is modelled, including inputs, outputs and equations.

**Table 13: Test results wind modelling methods**

| | Hepburn Wind | Method B | Method C |
|---|---|---|---|
| Energy Generation (MWh/y) | 12200 | 7601.7 | 10015.9 |
| Margin of error | 0% | 38% | 18% |

For the Mini-Wind option, Method B was applied to a 10kW mini-wind turbine. Method B was chosen over Method C because the data used in Method C is based on large wind turbine industry data, and is thus not appropriate for small wind-turbines which are less efficient. Figure 21 is a detailed flowchart outlining exactly how the mini-wind option is modelled, including inputs, outputs and equations.

It was envisaged that CEDAT users would have the option to scale the size of wind and mini-wind systems proposed, based on land availability, one of the key site specific variables. However, due to the complexity of reverse calculating energy use based on land availability using Method C and time constraints, this function is not available in the current version of CEDAT.

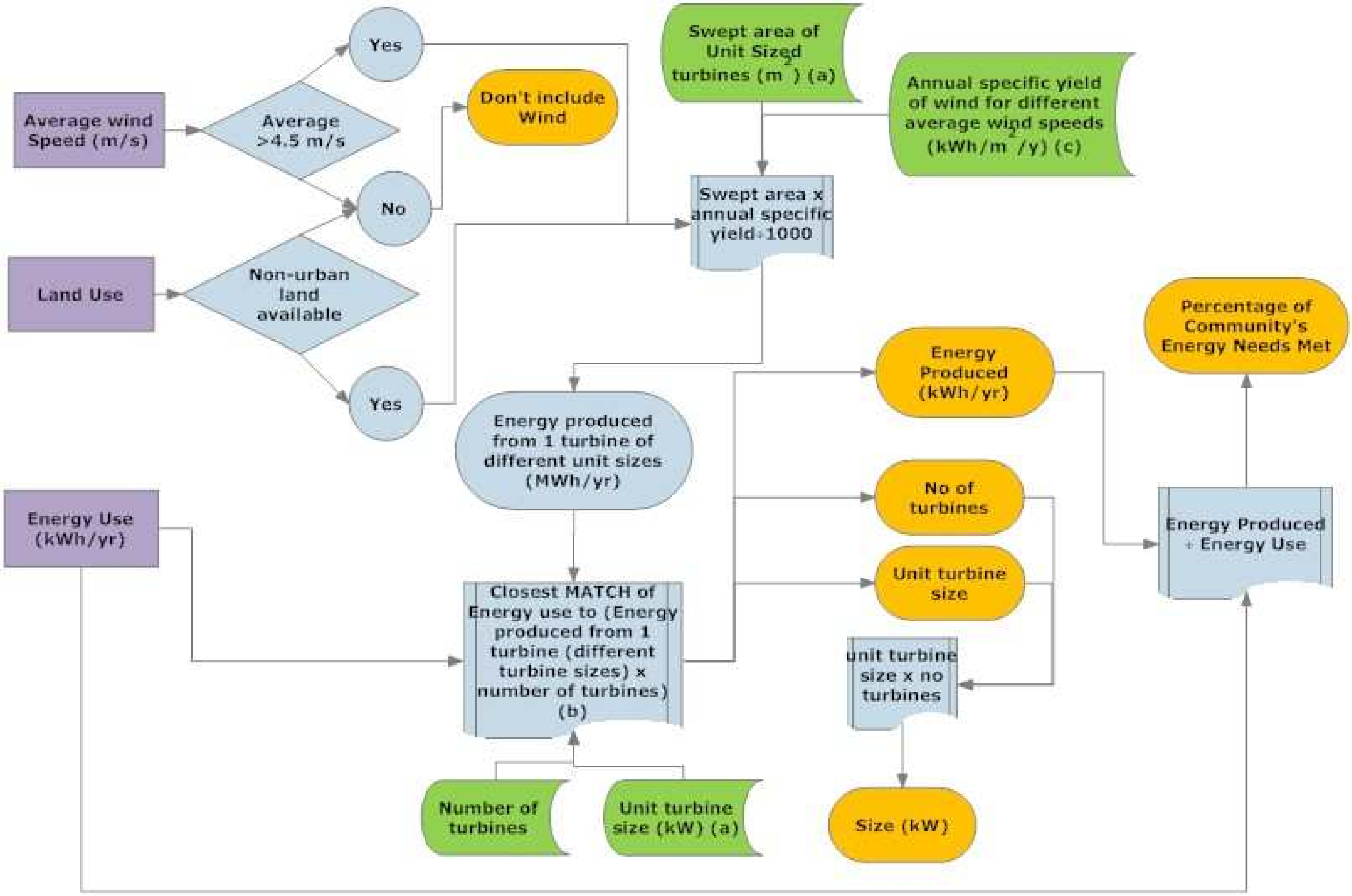


**Figure 20: Wind modelling flowchart**

(a) The unit turbine sizes and corresponding swept areas are given in Table 12

(b) Method C outlined above

(c) The annual specific yields for different average wind speed takes is detailed in Table 11

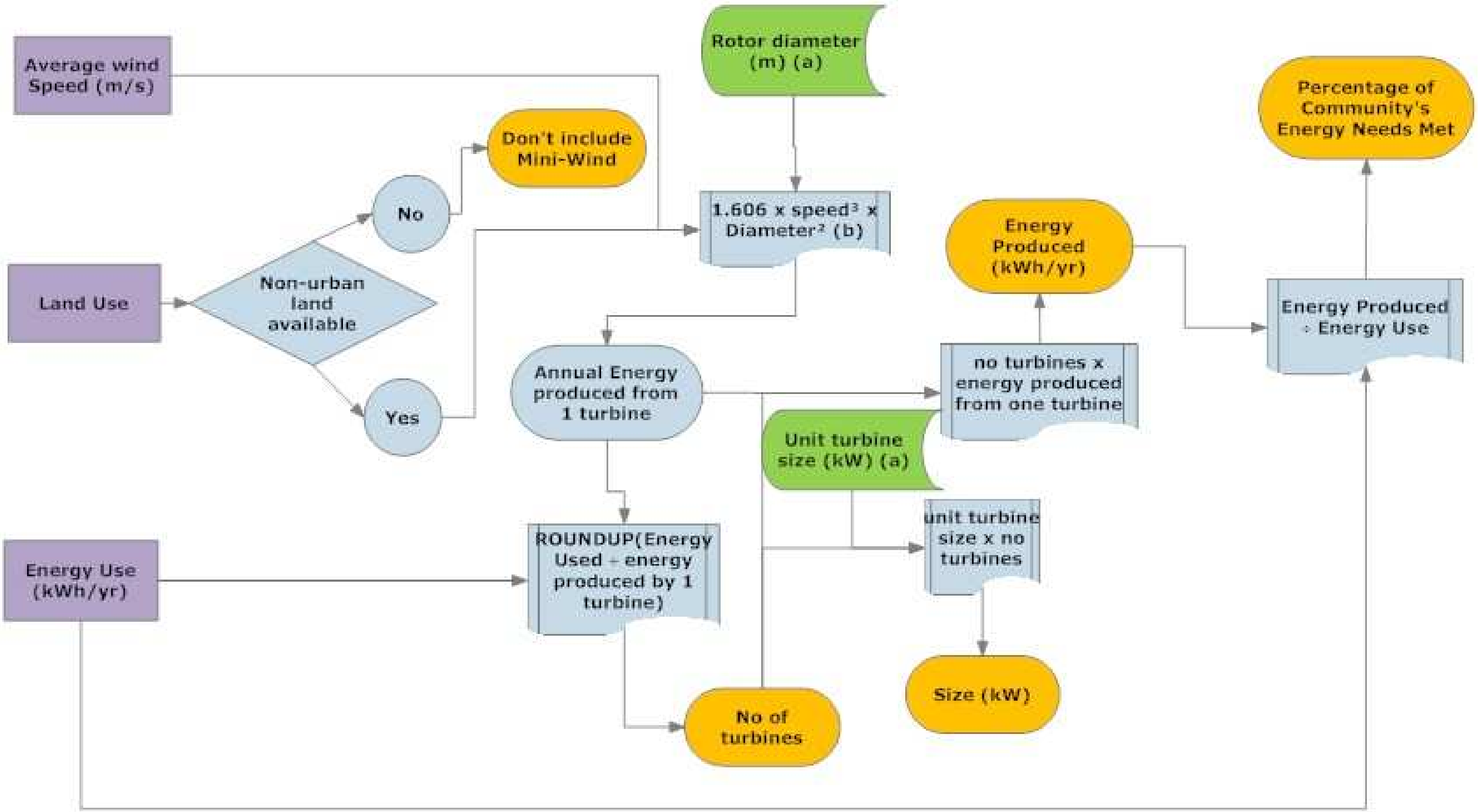


**Figure 21: Mini-wind modelling flowchart**

(a) Although there are many different mini-wind turbine sizes and configuration, a standard 3-blade 10kW turbine is used as the unit sized mini-wind option. 10kW turbines have a rotor diameter of 8m (ECVV, 2009)

(b) Equation X is used to calculate annual energy production from 1 turbine

### 7.2.2. SOLAR PV

Modelling of solar PV builds on the information determined in the technical review and energy use modelling sections. They specified the key user defined inputs for solar PV as solar insolation and community energy use. The solar insolation input was constrained by data available in the Renewable Energy Atlas, specifically an annual average solar exposure ($MJ/m^2/day$). The desired outputs were also known – energy use (MWh/yr), size of project (MW) and number of solar panels. Thus, the unknown component was the solar PV energy modelling method. Of the modelling techniques described in the literature, the most commonly used was the application of Equation 5 (Sydney Energy Co-op pers comms, 2009, Solar Energy Industries Australia, 2009, Messenger and Gosswani, 2007 and Stapleton et al, 2008).

**Equation 5**

$$DEO = \eta \, psh$$

Where:
DEO = Daily energy output in kilowatt hours of a 1kWp PV array.
$\eta$ = efficiency of the inverter and wires associated with the PV array
psh = peak sunshine hours

Fortuitously, Equation 5 calculates the desired outputs based on the available inputs. Specifically, psh is an indicator of sunlight intensity and is found by dividing average daily solar insolation (converted to $kWh/m^2$) by peak sun intensity, which is defined as 1 $kW/m^2$. Psh is equivalent to the average daily insolation figure given in the Renewable Energy Atlas (Messenger and Gosswami, 2007). This approach is limited as it does not consider variability of solar insolation during the year, however it is sufficient for CEDAT. Figure 22 is a detailed flowchart outlining the process for modelling energy generation of the solar PV option.

For the Solar PV option, users are also given the option to refine the size of the proposed system based on another important locational variable. In a community, particularly an urban community available north facing, unshaded space is likely to be a major constraint to the amount of PV that could be installed. Estimating this space availability was considered unnecessary for the initial CEDAT process, however if communities wish they can incorporate this knowledge through the sizing process.

For PV Sizing the inverse of the equations outlined in the flowchart (Figure 22) are used and instead of energy being constrained and space calculated, space is constrained and energy is calculated.

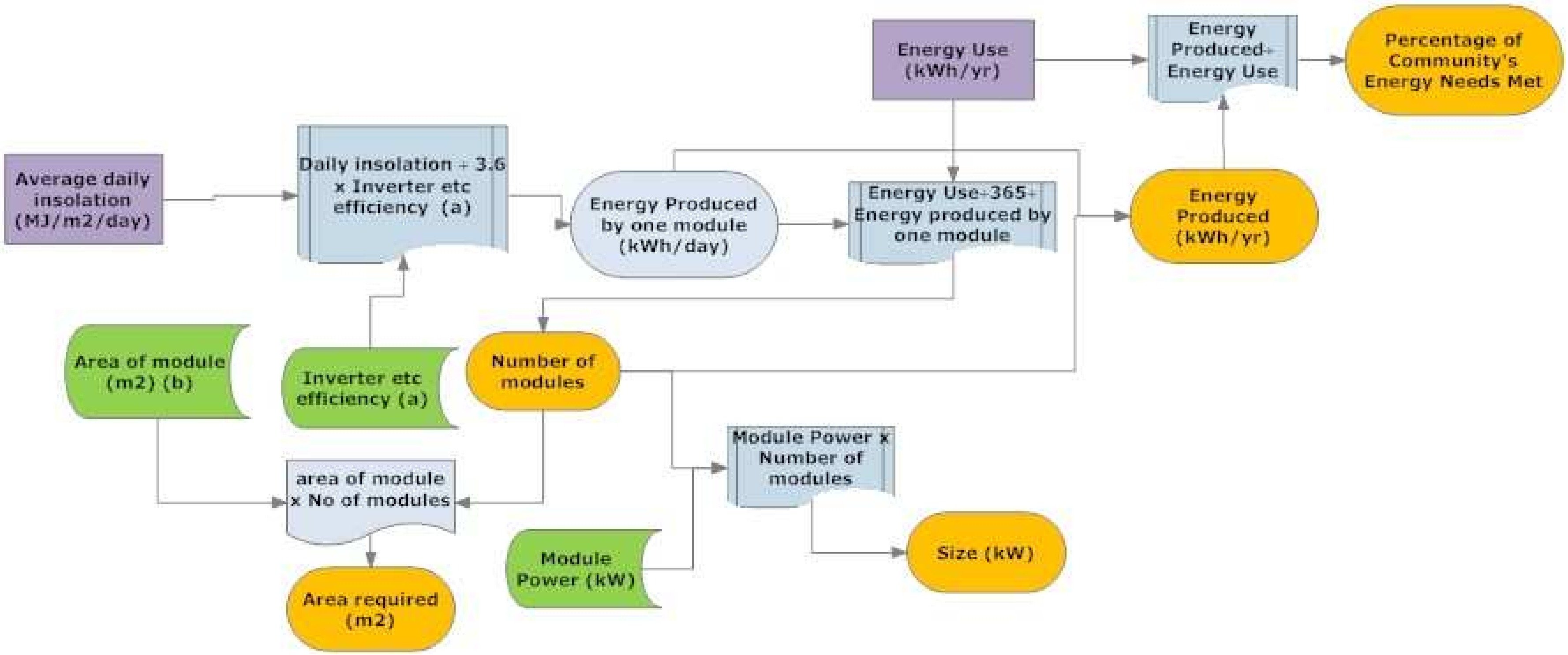


**Figure 22: Solar PV modelling flowchart**

(a) A 1kW system is taken to have an active area of 16.8m² (SEIA, 2009)

(b) Efficiency of the inverter and wires is taken as 75% (SEIA, 2009

### 7.2.3. BIOMASS

The biomass modelling process builds on the information determined in the technical review and energy use modelling sections. They specified the key user defined inputs for biomass as access to sustainable biomass and community energy use. The desired outputs were also known – energy use (MWh/yr), size of project (MW) and amount of biomass required. Thus, the unknown component was the biomass modelling process. There were a two modelling processes outlined. The first was a bioenergy engineering approach which considered calorific values of the fuels and technology efficiency factors. The second was the standard energy planning approach ((Equation 6). Given data availability the second approach is used in CEDAT. Figure 23 is a detailed flowchart outlining the process for modelling energy generation of the agricultural biomass option.

**Equation 6**

$$\text{Size} = E \div (CF \times 8760)$$

Where:
Size = plant size in MW
E = Annual energy production in MWh
CF = capacity factor, which is the ratio of energy a technology does produce compared with what it could produce at maximum power and is a standard industry value associated with specific technologies
8760 = number of hours in a year

This approach assumes that the amount of biomass available is not a constraint and is calculated using the approach detailed in Note a. This assumption was made because there is no publicly available dataset that provides location-specific biomass resource assessments. As such, biomass availability was deemed too difficult a question to require all potential CEDAT users to answer. However, the assumption is not always valid, particularly as there are a number of sustainability concerns associated with using biomass as a fuel for generating electricity (Section 6.3.4). So if the biomass demand calculated by CEDAT is unavailable, suitability of biomass as a technology option for a community energy project is diminished. Thus, users are given the option to specify the amount of sustainable biomass available.

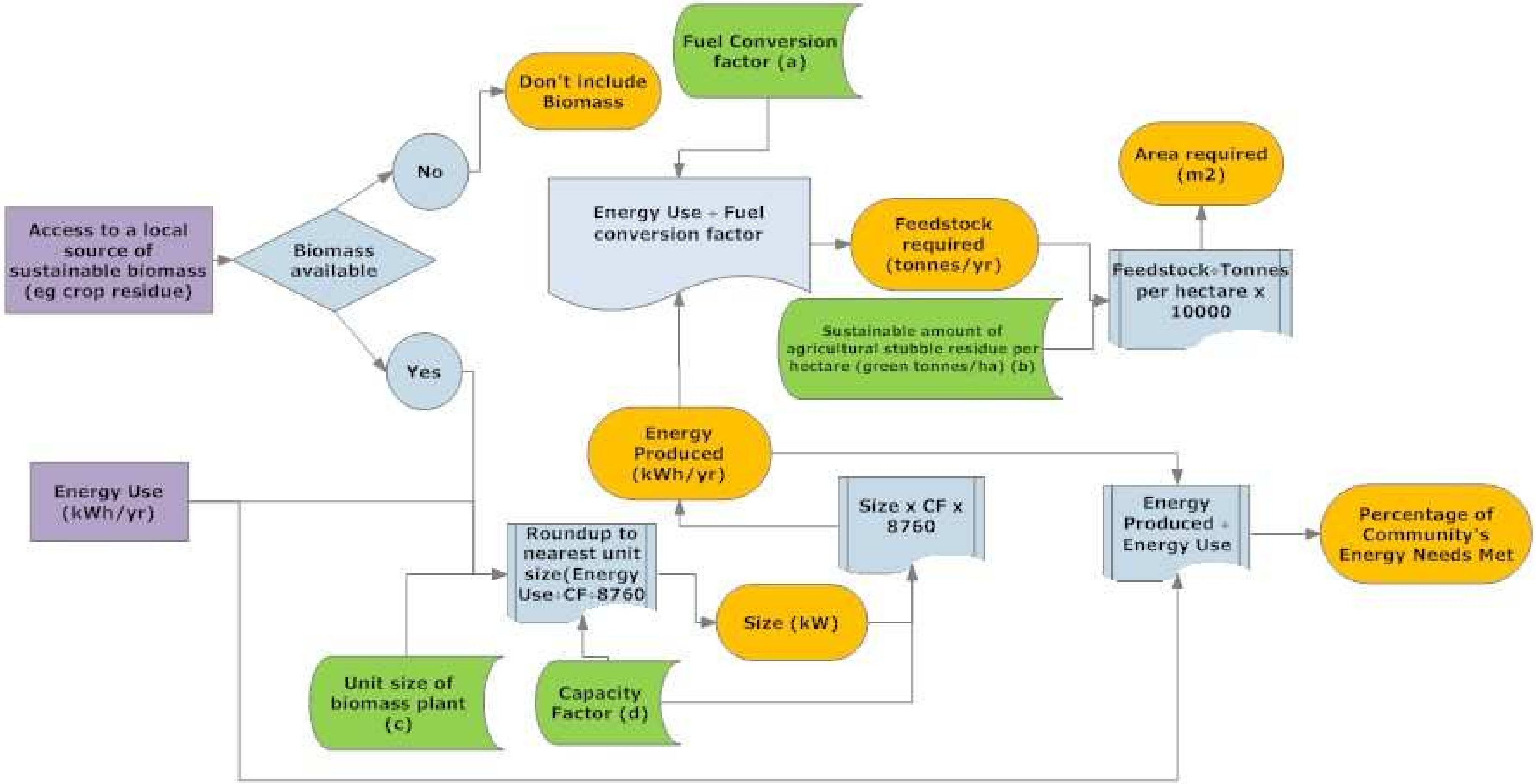


**Figure 23: Bioenergy modelling flowchart**

(a) The fuel conversion factor is based on RIRDC, 2008, assumption that 0.8wet tonnes of biomass are required to produce 1MWh of electricity

(b) Diesendorf (2007), reports that the agricultural scientist FM Kelleher estimates that there are 3.4 wet tonnes of harvestable grain crop stubble residue per hectare of crop per year and that 1 tonne of this will be retained on the land to maintain the structure of the soil. Thus, the sustainable biomass yield for an area is taken to be 2.4green tonnes per hectare.

(c)The unit size of a biomass plant is taken to be 100kW.

(d) The capacity factor of a biomass plant is taken to by 75% from Glassmire et al (2009).

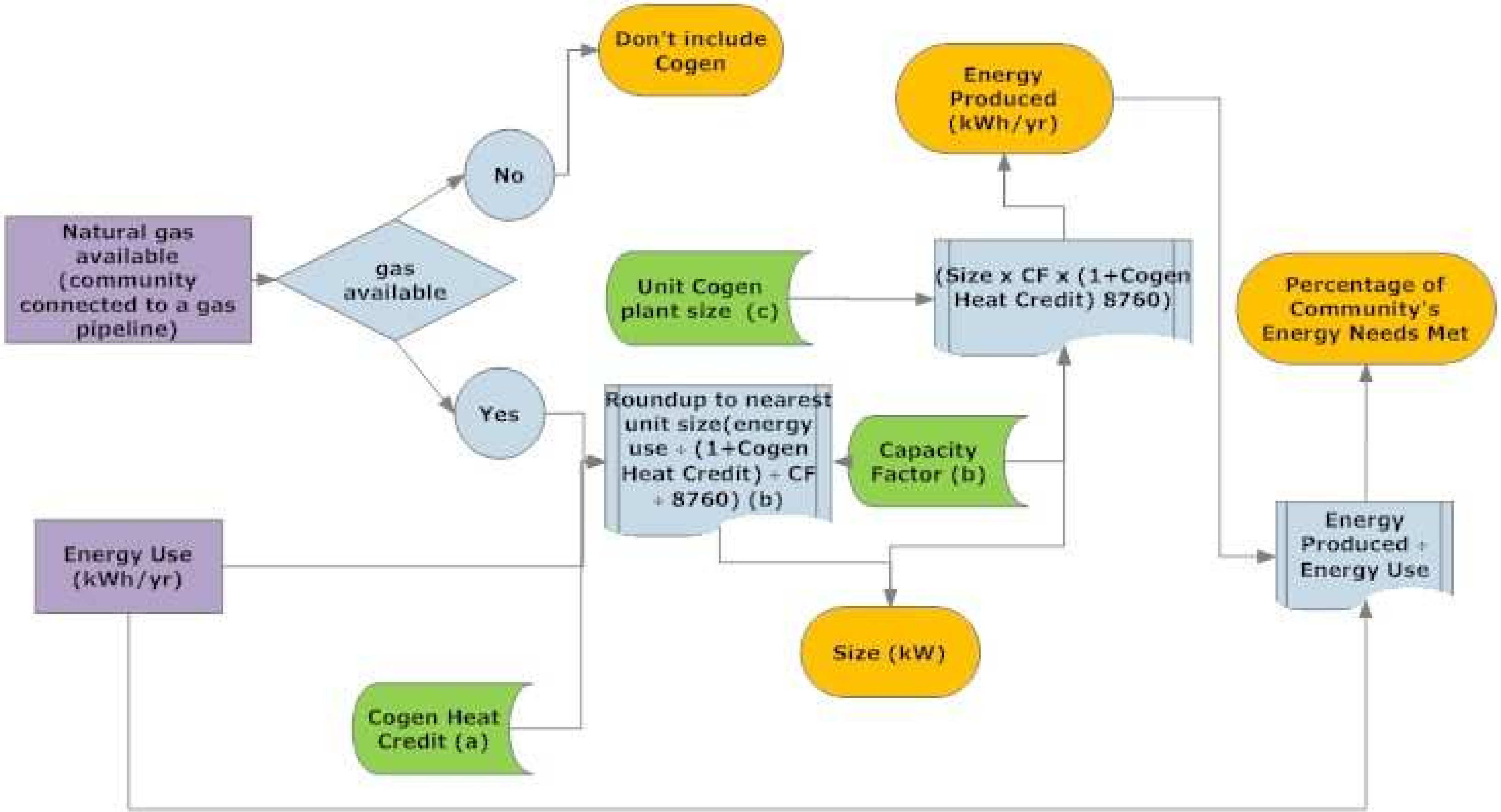


**Figure 24: Cogeneration modelling flowchart**

(a)The cogeneration heat credit is the amount of heat energy utilized from a cogeneration plant as a percentage of the energy generation capacity. It is taken to be 30% based on Glassmire et al, 2009.

(b) The process of calculating the appropriate size of cogeneration plant uses the standard energy modelling approach. The cogeneration capacity factor used in CEDAT is 85%

(c)The minimum size of a cogeneration plant is assumed to be 10kW, based on Turner (2007), it is also assumed that cogeneration plants can scaled up in 10kW increments.

### 7.2.4. COGENERATION AND TRIGENERATION

The cogeneration modelling builds on the information determined in the technical review and energy use modelling sections. They specified the key user defined inputs for cogeneration as access to natural gas and community heating, cooling and electricity loads. The desired outputs were also known – energy use (MWh/yr) and size of project (MW). Thus, the unknown component was the cogeneration modelling process. Similarly to the bioenergy option, the two modelling processes outlined in the literature were very technical cogeneration engineering approach and the standard energy planning approach, the latter of which was applied in CEDAT. However, the added modelling factor associated with cogeneration is the need to consider not just electricity produced, but also useful heat. For simplicity a fixed heat credit was used to determine how much useful heat is produced as a percentage of electricity generated. However, it is difficult to fully optimize the size of a cogeneration plant to meet electricity, heating and cooling requirements of a community. As such, it was initially assumed that the cogeneration plant will meet a community's heating and cooling needs partially with electricity and partially with useful heat through a medium such as climate water. This process means that the cogeneration plant is a net exporter of energy. Figure 24 is a detailed flowchart outlining this process for modelling energy generation from a natural gas fired cogeneration plant.

An option to resize the cogeneration plant is also given. This option allows users to match a community's heating and cooling needs to the useful heat produced by a cogeneration plant, thus optimizing plant size around heat rather than electricity. This however, often means that not all of a community's energy needs are met, given that the heat credit is only 30%. DEWHA (2008) data is used to calculate the heating, cooling and electricity loads in the community, by state.

## 7.1. ENVIRONMENTAL ANALYSIS

The environmental impact of energy technologies is one of the main motivations for the development of community energy projects (Walker, 2008). As such, an environmental analysis of the technology options is an important component of CEDAT. The technical review outlined a number of environmental considerations associated with the technology options. In ESAT (SAP, 2008), the environmental indicators or outputs calculated were energy, water use, greenhouse emissions, footprint and nutrients. However, to estimate these variables a full life cycle analysis would have to be undertaken. Given the scope and time constraints associated with this research, it has not been possible to find or determine lifecycle analysis data on all five technologies. As such, the only environmental indicator or output that CEDAT calculates is carbon emissions abatement potential of each technology. This indicator is particularly important as community energy projects are defined as projects that decarbonise our energy system. Emissions abatement potential is calculated using Equation 7 as shown in Figure 25.

**Equation 7**

$$\text{Emissions Abatement} = (SEF - TEF)AEO$$

Where:

Emissions abatement is in tonnes $CO_2e$/year

SEF= Scope 2 Emissions Factor for the electricity pool in the specified state (tonnes $CO_2e$/MWh) (Table 14)

TEF= Scope 2 Emissions Factor for the specified technology (tonnes $CO_2e$/MWh) (Table15)

AEO = Annual energy output (MWh/year)

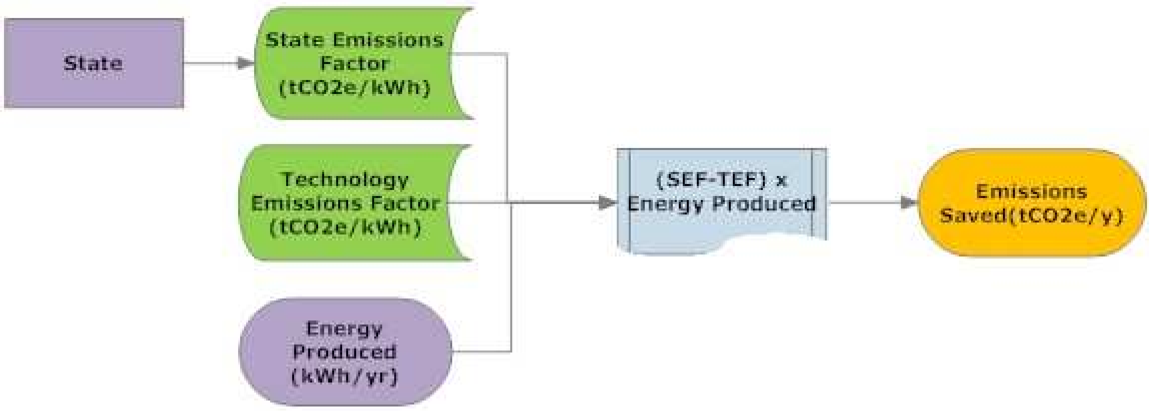


**Figure 25: Emissions abatement modelling flowchart**

The international greenhouse gas accounting framework defines greenhouse gas emissions as either Scope 1, 2 or 3 (DCC, 2009). Scope 1 emissions are defined as Direct (or point-source) emission, specifically the amount of carbon dioxide equivalent (CO2-e) emitted per unit of activity at the point of emission release (i.e. fuel use) (ibid). Scope 2 emissions are defined as the emissions from the generation of the electricity purchased and consumed by an organisation as kilograms of CO2-e per unit of electricity consumed. Scope 2 emissions are physically produced by the burning of fuels (coal, natural gas, etc.) at the power station (ibid). Scope 3 emissions factors are the emissions associated with the lifecycle of a product for example the extraction of fossil fuels. Whether emissions are defined as Scope 1, 2 or 3 depends on the frame of reference. For this research the frame of reference is the end user in the community, as such the emissions factors used for both CEDAT technology option and pool electricity are Scope 2. Scope 3 emissions are available for the Australian electricity pool by state are not used. The rationale for their exclusion in CEDAT is that the equivalent information is not easily available for the technology emissions factors and thus if used would unfairly bias the emissions abatement potential towards the technologies in CEDAT. The emissions factors used are given in Table 14 and Table 15.

In addition, to emissions abatement there are environmental impacts associated with these technologies that are hard to quantify. Instead the environmental information gathered as part of Section 6, is detailed in Technology summary pages in CEDAT, which are discussed in further detail in Section 7.4.

**Table 14: State Scope 2 emissions factor (DCC, 2009)**

| State | Scope 2 Electricity Emissions factors (tonnes $CO_2$/MWh) |
|---|---|
| ACT | 0.89 |
| New South Wales | 0.89 |
| Northern Territory | 0.68 |
| Queensland | 0.9 |
| South Australia | 0.83 |
| Tasmania | 0.13 |
| Victoria | 1.23 |
| West Australia | 0.84 |

**Table 15: Technology Scope 2 emissions] factors (Glassmire et al, 2009)**

| Technology | Emissions factor |
|---|---|
| | [tCO2e/MWh] |
| Wind | 0 |
| Solar PV | 0 |
| Cogeneration | 0.3 |
| Agricultural biomass | 0 |
| Mini Wind | 0 |

## 7.2. ECONOMIC ANALYSIS

As discussed in the Section 6, two of the main economic variables considered when designing a new project are capital cost and unit cost. However, there are also additional economic variables that are likely to be of interest to communities developing an energy project. As such, CEDAT provides an estimate for the following economic variables:

- Capital cost ($)
- Unit cost ($/MWh)
- Subsidy available under current policy conditions ($/y);
- Cost of the project per household per year ($/y); and
- Household cost comparison between doing the project and business as usual per (%).

The base data used to generate these outputs is specified in Section 6.6. The modelling process in CEDAT to generate these five economic variables is depicted in Figure 26.

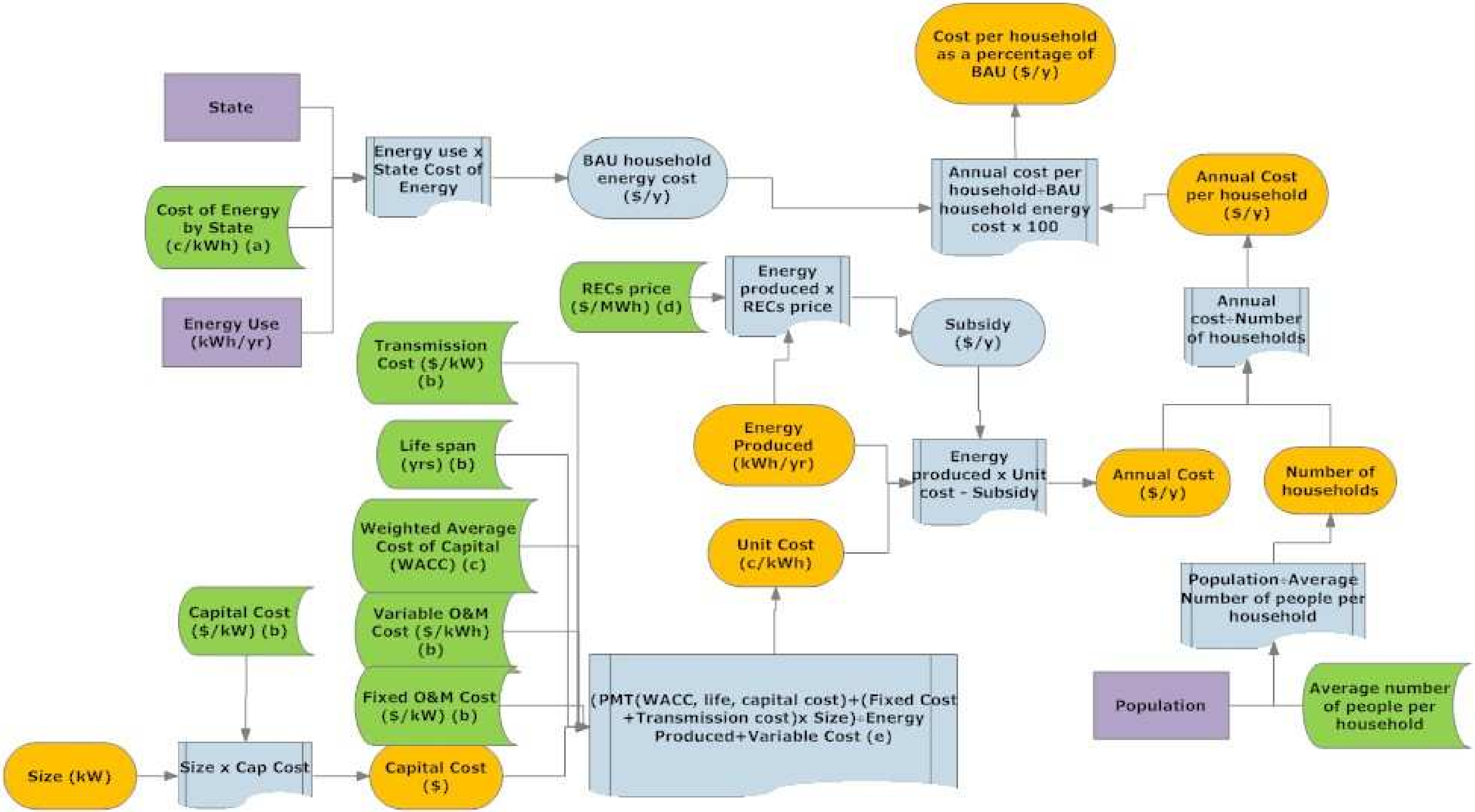


**Figure 26: Economic analysis flowchart**

(a) Cost of energy per state, is the cost of a community's energy – electricity, gas and wood with no project, detailed in Section 7.2.2.

(b) Cost figures and life of capital from Table 9

(c) Weighted average cost of capital (WACC) is an interest rate variable that accounts for the time value of money. In CEDAT it is assumed to be 6%.

(d) RECs are Renewable Energy Certificates; they are explained in Section 7.2.1. The price of a REC is taken to be $40, the average from CEC Market Wrap, 2009.

(e) PMT is an MS Excel formula that in this context calculates the payment for the unit price of electricity, based on constant payments and a constant interest rate (WACC)

### 7.2.1. SUBSIDIES

A brief analysis of subsidies available for community energy projects yielded two relevant policies – state based Feed-in Tariffs (FiT) and the federal Renewable Energy Target (RET).

FiTs work by governments specifying a price for electricity generated from renewable energy sources. Currently there are FiTs in place or announced in all states and territories except the Northern Territory and Tasmania. However, the policy specifics as to which technologies are eligible, the size of system eligible and tariff rate vary from state to state (CEC, 2009). Due to the complexity of incorporating so many different policies and time constraints, subsidies available to community energy projects associated with FiTs are not considered in CEDAT.

The RET works by legislating that a certain amount of Australia's energy be sourced from renewable energy by a particular date, specifically 12,500GWh in 2010 rising to 45,000 GWh in 2020 (CECa, 2009). This policy works by creating a market where Renewable Energy Certificates (RECs) are the currency. Every megawatt hour of electricity generated by a renewable energy generator is eligible for a Renewable Energy Certificate (REC). As such, if a community pursues an energy project utilizing any of the technologies included in CEDAT except cogeneration, once operational it will earn income through the sale of RECs. The subsidy available to communities resulting from the sale of RECs is included in CEDAT as shown in Figure 26.

One feature of the 2009 amendment to the *Renewable Energy (Electricity) Act* specifies that the first 1.5kW of a renewable energy system are eligible for five RECs per MWh produced, providing a significant additional subsidy for small scale systems. This multiplier for small-systems has also been incorporated into CEDAT for the PV and mini-wind options.

### 7.2.2. BUSINESS AS USUAL HOUSEHOLD ENERGY COST

To compare the cost of undertaking a community energy project with the cost of doing nothing (business as usual), it was necessary to calculate the average annual cost of energy per household. This process was more complicated than outlined in Figure 26, as the household energy use data in CEDAT aggregates electricity, gas, LPG and wood energy use. As such, unit energy cost data for wood, gas and electricity for each state was sourced (Table 16), LPG is ignored as it represents such a tiny fraction of household energy use, less than 4%. The figures listed are averages, actual costs vary widely within a state; wood particularly is expensive in urban areas, but often free in rural locations. Using the data in DEWHA (2008), it was also possible to determine the percentage of household energy use that each of energy sources accounted for (Table 16). This table is the basis for calculating business as usual cost of energy for households in CEDAT.

**Table 16: State-by-state household energy use by source and associated costs (DEWHA 2008a, Office of the Tasmanian Economic Regulator, 2009, Todd, 2005)**

| State | % Elec | Cost of electricity - Standard (c/kWh) | % Gas | Cost of gas - (c/MJ) | % Wood | Cost of wood - ($/tonne) |
|---|---|---|---|---|---|---|
| ACT | 0.38 | 16 | 0.57 | 2.2 | 0.04 | 90 |
| New South Wales | 0.67 | 18 | 0.18 | 1.9 | 0.13 | 185 |
| Northern Territory | 0.93 | 19.8 | 0.03 | --- | 0 | --- |
| Queensland | 0.86 | 17.2 | 0.06 | 3.1 | 0.05 | --- |
| South Australia | 0.52 | 21.3 | 0.29 | 2.9 | 0.17 | 100 |
| Tasmania | 0.4 | 18.5 | 0 | 1.9 | 0.57 | 50 |
| Victoria | 0.27 | 17.7 | 0.6 | 1.5 | 0.12 | 110 |
| West Australia | 0.51 | 19.1 | 0.32 | 3.0 | 0.13 | 85 |

## 7.3. MULTI-CRITERIA DECISION ANALYSIS

CEDAT is designed to function as part of an MCDA process. As outlined in the Section 5.2, MCDA is a process for decision makers to analyse information regarding multiple and often competing objectives for many options and incorporate the results into their decisions. These objectives are represented by quantifiable criteria which can be scaled and synthesised into a final score for each option. Thus, there are two important considerations in modelling the MCDA in CEDAT – the criteria and the scaling and synthesising algorithms; these two considerations are discussed in the sections below.

**MCDA Criteria**

Given the STEEP framework has been used extensively in this thesis and that it provides a holistic analysis of a topic, incorporating criteria associated with all five STEEP factors was initially considered. However, after discussion with potential CEDAT users, it was clear that their objectives and the useful information that they wanted CEDAT to determine did not nicely fit into the five STEEP categories. Instead it was determined that the MCDA for the five technical options in CEDAT should include:

- Economic criteria, specifically capital cost and annual cost per household have been chosen. Capital cost is typically the most significant cost for communities while annual cost per household considers both unit cost and subsidies available and makes it tangible for users by using a household unit.
- An environmental criteria, specifically emissions abatement potential as it is the only one that CEDAT calculates.
- The socio-technical variable of complexity (introduced in Section 6).

Unlike the cost and emissions abatement criteria, complexity of the technology options is not calculated in CEDAT. Instead, a number has been assigned to represent the degree of complexity, these are detailed in Table 17, with the associated rational. These assigned values are defaults based on my informed opinion and can be changed by users at their discretion.

**Table 17: Complexity rankings assigned to the technology options in CEDAT**

| Technology Option | Complexity | Rational |
|---|---|---|
| Solar PV | 100 | Solar PV is the simplest technology, it needs little maintenance and has no moving parts |
| Mini-wind | 80 | Mini-wind is of a scale that it is easy for people to learn how to maintain it with minimal training |
| Wind | 60 | Wind turbines require expert training to maintain, however they do not require people to operate. |
| Cogeneration | 40 | Multiple different technologies are involved in a cogeneration plant adding to the complexity. |
| Agricultural biomass | 30 | The variability and handling requirements of the biomass resources in addition to multiple different complex technologies, make agricultural biomass the most complex technology considered |

**Scaling and synthesising algorithms**

In the MCDA process to determine the weighted total score for an option, a performance matrix was constructed (Figure 27). A scaling algorithm and weighting was then applied to each criterion independently. The total score for each option was then calculated using Equation 8 (discussed in Section 5.2).

**Equation 8**

$$S_i = w_1 s_{i1} + w_2 s_{i2} + \ldots + w_n s_{in} = \Sigma w_i s_{ij}$$

To determine the weights for each criterion a user input field was set up. It requires users rank each criteria out of 10, where 10 is the most important and 0 the least.

Two methods were investigated for scaling the performance scores of each criterion – Min-Max and Range. In the Min-Max approach, the option with the best indicator score for a specific criterion (e.g. lowest capital cost) is assigned 100, the worst (e.g. highest capital cost) is assigned 0, while the remaining options are assigned a value between 0-100 based on linear scaling (DCLG, 2009). The benefit of this approach is that it is very simple; however, it can distort the picture as some criteria may have much larger ranges, which are not reflected in the min-max algorithm.

The Range approach is similar to the Min-Max approach however the best and worst indicators are set to what is desired (ibid). For example, for the capital cost criteria a maximum and a minimum capital cost are specified and all options are scaled linearly between. While this process has the benefit of removing the issue of different ranges, assigning a maximum and minimum value for each criteria is almost impossible in CEDAT given that the scale of the economic and environmental criteria are determined by user inputs and thus vary widely.

**Multi Criteria Decision Analysis Calculations**

| Technology Option | Emissions savings | Capital cost | Annual household cost | Complexity | Weighting |
|---|---|---|---|---|---|
| Wind | 100 | 23 | 6 | 60 | 53.8 |
| Solar PV | 27 | 0 | 0 | 100 | 31.1 |
| Cogeneration | 0 | 100 | 100 | 40 | 53.3 |
| Agricultural biomass | --- | --- | --- | 30 | --- |
| Mini wind | 28 | 73 | 68 | 80 | 58.6 |
| **Weighting** | 0.33 | 0.26 | 0.19 | 0.22 | |

**Project criteria user weightings**

| Emissions savings | Capital cost | Unit cost | Complexity |
|---|---|---|---|
| 9 | 7 | 5 | 6 |

Figure 27: CEDAT MCDA performance matrix

Given the options available and their relative benefits and limitations, CEDAT uses a Min-Max scaling algorithm in line with the goal that CEDAT be a simple and transparent tool for users.

## 7.4. USABILITY OF CEDAT

The final element involved in the development of CEDAT, was to make it easy to use and ensure the outputs were in a useful format. This involved:

- Designing and writing an easy to understand an introduction page and users guide;
- Coding macro buttons to guide users through the process; and
- Providing summary sheets for each technology option.

Each technology option has a separate summary sheet. They include the outputs related to that technology calculated in CEDAT, additional technical, economic and environmental considerations and links to resources where users can find out more information.

## 7.5. SUMMARY OF CEDAT

In summary, CEDAT was designed for community groups/organisations that are in the initial stages of developing a community energy project. Its purpose is to provide a framework for users to better understand low carbon technology options suitable for a specific community and to target further investigation. CEDAT does this through five main modelling components and by incorporating user friendly features such as technology option summaries. The modelling of CEDAT involved:

- An energy use model, which estimates a community's energy use
- Energy generation models for all five technologies incorporated into CEDAT, scaled around community energy use and/or local resource constraints such as biomass availability
- Environmental modelling, which calculates and compares the emissions abatement potential of each of the five technology options in CEDAT
- Economic modelling that calculates and compares capital and unit costs, subsidies available, annual household and annual household cost as a percentage of business as usual
- A multi-criteria decision analysis process that uses a Min-Max scaling algorithm applied to four criteria – complexity, annual household and capital costs and emissions abatement potential. These are then combined to generate a weighted total score for each technology option.

Screenshots of the worksheets in CEDAT are provided in Appendix B, these summarise the inputs and outputs of the five modelling components. Additionally, the CEDAT model is provided in a CD accompanying this report.

In conclusion, it is envisaged that if CEDAT fulfils its specified purpose, technical knowledge constraints that communities face will be partially removed. Exploring this proposition is the basis for the next chapter.

# 8. APPLICATION OF CEDAT – SYDNEY COASTAL ECOVILLAGE CASE STUDY

A preliminary assessment of CEDAT was undertaken to ascertain if it was useful for community energy proponents. To this end, CEDAT was applied to a case study of the Sydney Coastal Ecovillage

## 8.1. SYDNEY COASTAL ECOVILLAGE BACKGROUND


**Figure 28: Proposed Sydney Coastal Ecovillage Site – Research Rd, Narara, NSW**

The Sydney Coastal Eco-village (SCEV) is planned as sustainable community on the Central Coast of NSW. Currently the project is in the initial planning stage, and has over 20 active members.

The mission of SCEV is "to research, design and build a stylish, inter-generational, friendly demonstration ecovillage near the coast not too far from Sydney, blending the principles of eco and social sustainability, good health, business, caring and other options that may evolve for our well being" (Boo, 2009). The current proposed site for SCEV is Narara, NSW as shown in Figure 28.

SCEV was chosen as a case study to trial CEDAT for a number of reasons. Firstly, it is a community that is seeking to source its energy from low carbon sources. Secondly, although energy is a critical component of the overall planning process the project proponents had yet to consider it in any detail. Thirdly, there are few communities proposed or existing within easy distance of Sydney planning a community energy project, hence it was an obvious site for a trial of CEDAT. Finally, the planning committee of SCEV includes a range of people with different backgrounds and different knowledge bases regarding energy and a framework to share knowledge. An ability to work towards a decision was identified as useful by the project proponents.

## 8.2. CASE STUDY RESEARCH METHOD

Undertaking a case study of the Sydney Coastal Ecovillage involved designing a process that would be accessible and useful for both myself as the researcher and members of SCEV. The following three step method was developed:

1. Initial correspondence and conversations with the two lead proponents of SCEV – David and Lyndal Parris. This provided me with necessary background to determine the viability of SCEV as a case study and to design the remaining aspects of the case study methodology.
2. A workshop I facilitated for seven members of the SCEV planning committee. This workshop took the participants through a modified version of the phases involved in the WSAA Framework (Lundie et al, 2008). Specifically this process included:
    a. An introduction to members of the committee and the establishment of the SCEV context;
    b. Setting objectives for the SCEV community energy project;
    c. Distillation of the objectives into criteria that could form the basis of an MCDA;
    d. Trailing CEDAT to determine preliminary results of an energy technology options assessment; and
    e. Discussion, evaluation and feedback on the workshop process and outcomes.
3. A working version of CEDAT was emailed to interested workshop participants so they could trial it individually and provide further feedback.

Additionally, I have committed to writing a report for SCEV regarding their energy options; however the report is beyond the scope of this thesis.

## 8.3. SYDNEY COASTAL ECOVILLAGE ENERGY CONTEXT

The energy context for a community such as SCEV includes social and physical factors. Specifically discussed through the workshop were the backgrounds and motivations of SCEV members to be involved in the project. The backgrounds of workshop participants ranged from an accountant and retiree to a farmer and two architects. Additionally, two workshop participants work in the energy sector. The motivations for those involved included a commitment to environmental sustainability (Female 1[13]) and triple bottom line sustainability – social, economic and environmental (Female 2 and Female 3) as well as an

[13] To maintain the confidentiality of workshop participants, they are referred to by code – Female/Male 1 etc.

interest in community "in the real sense of the word" (Male 1, Female 3 and Female 4). One participant cited that the energy company he worked for was not doing as much as it could and thus he wanted to be involved in a project that would create change (Male 2).

Physical context considerations discussed include the fact that the proposed site – Lot 1, DP 1087535, Research Road, Narara (Figure 28) is in a sunny valley, surrounded by trees and thus not very windy. It is currently electricity grid connected but not gas connected. There is a small creek and a dam with some head and also some agricultural biomass available. It was identified that the largest non-residential energy loads will be pumping loads for water and wastewater on site. Initial thinking is that solar pumps would be appropriate for these loads because as long as there is sufficient storage, they can switch on whenever the sun is shining. Another consideration is that there are few existing buildings on the site, but most residences for SCEV community members will be built as part of the eco-village development process; they will employ passive solar design, minimizing the community's energy needs.

## 8.4. SYDNEY COASTAL ECOVILLAGE COMMUNITY ENERGY PROJECT OBJECTIVES

Through the workshop process, based on the outlined energy context, the following five objectives were determined for energy at SCEV.

1. To minimize the need for energy through solar passive design
2. For all energy to be produced from renewable/sustainable sources
3. For the community either to be grid connected and a net producer of electricity or 100% energy self sufficient (this objective is discussed more in Section 8.6)
4. For the community to be a demonstration site for sustainable energy technologies, specifically innovative technologies matched to specific energy loads
5. For the energy project financing arrangement to minimize the need for strata fees.

Of these five objectives, it was identified that the application of CEDAT could assist with information regarding which renewable or sustainable sources were feasible; how much energy might be required to be a net producer of electricity; and how much different energy options might cost. However, it was clear that to provide information that would meet all objectives was beyond the scope of this research, as a site specific study would have to be undertaken to examine all potential energy options from household to community scale.

## 8.5. CRITERIA FOR ASSESSING TECHNOLOGY OPTIONS FOR SYDNEY COASTAL ECOVILLAGE

To undertake a preliminary options assessment for energy at Narara, the participants discussed which criteria would be useful given the objectives set. The criteria decided on are detailed in Figure 19.

**Table 18: Sydney Coastal Ecovillage MCDA Criteria**

| Criteria | Rational |
|---|---|
| Annual carbon emission abatement (tonnes $CO_2$e/y) | Carbon emissions are an indicator of environmental sustainability, which was a key motivator for many members of the SCEV community and was referenced in two of the objectives. |
| Capital cost ($) | Was considered important so it is affordable to develop the community and have people live there |
| Annual household energy cost | Was considered important as this refers to all costs including subsidy available, and thus is relevant for minimizing the need for strata fees. |
| Technological complexity | Was considered important given that people in the community will have to maintain the energy system (discussed more in Section 8.6) |
| Embodied Energy | Was considered important as the sustainability of an energy technology is not restricted to its use phase, but is also related to its life cycle |

Of these five criteria, only embodied energy could not yet be assessed by CEDAT. This was discussed by the group and it was found acceptable to leave out embodied energy as an initial criteria.

## 8.6. CASE STUDY CEDAT INPUTS

During the course of the workshop there was discussion regarding how the energy technologies would be operated and maintained. This issue became significant when discussing the importance of the complexity criteria in CEDAT and thus what weighting should be applied. The interim decision made by the group was that the technology/technologies should be sufficiently simple that a few people in the community can understand and maintain them after training but not by so simple that they do not provide sufficient energy.  Based on this discussion complexity was assigned a weighting of six out of ten.

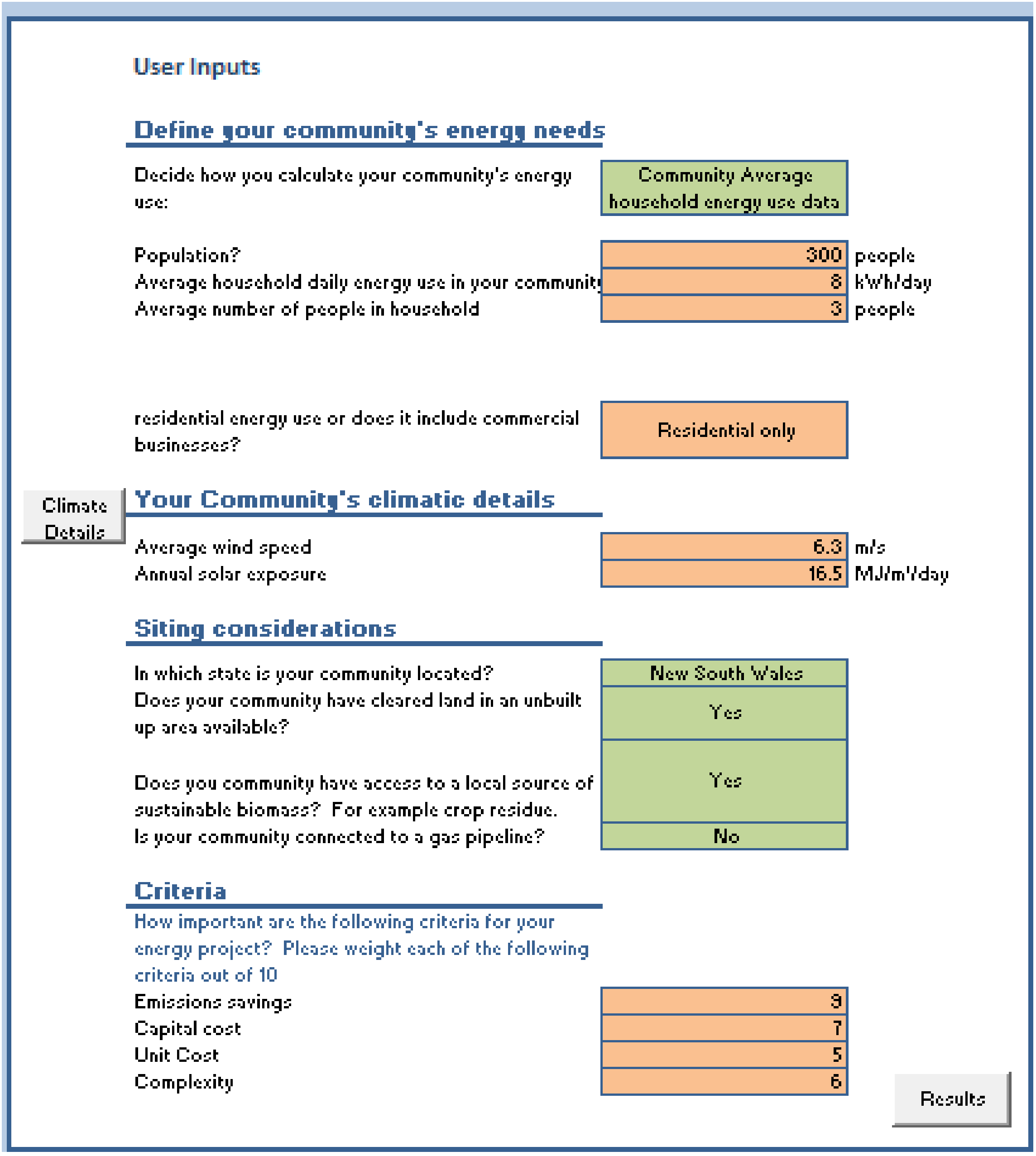


Figure 29: CEDAT User Interface with SCEV input values (Scenario 2)

Another discussion point regarded the necessity of a sustainable baseload power source at SCEV.  Two competing objectives were posed.  The first one proposed that SCEV be 100% energy self-sufficient.  The second one proposed that SCEV be a net exporter of electricity, but rely on the grid to meet demand needs, when onsite generation cannot.  The argument posed in support of being a net supplier and relying on the grid, is that the nature of technologies that can deliver baseload power are that they are considered less environmentally sustainable.  For example, the cogeneration option in CEDAT uses natural gas, which is a fossil fuel and thus many SCEV members considered it unsustainable.

However, the argument posed in support of SCEV being 100% energy self-sufficient is that by remaining grid-connected, SCEV is implicitly perpetuating the use of coal-fired electricity. This discussion was particularly relevant to determining how to answer the question in CEDAT as to whether the community should have access to a Natural Gas supply, given that the site is not currently connected to a gas pipeline. This question is significant as it determines whether the cogeneration option is considered for the community. However, this workshop could identify and pose this question but not resolve this complex issue. Hence, CEDAT was trialled with two scenarios, one with a natural gas supply option and the other without.

The remaining CEDAT inputs determined at the workshop are shown in Figure 29 (Scenario 2 – without gas). It should be noted that the climate data are sourced from the Renewable Energy Atlas, household energy use was estimated by one of the participants with an energy background and emissions savings were universally agreed to be the most important criteria, while annual household cost was the least. Additionally, the size of the biomass option was scaled to reflect that there is only approximately one hectare of arable land which could produce sustainable biomass (crop residue) onsite.

## 8.7. CASE STUDY CEDAT RESULTS

The MCDA results from applying CEDAT to two scenarios of the Sydney Coastal Ecovillage community energy project are summarised in Figure 30 and Figure 31. Under both scenarios Figure 30 and Figure 31 show that mini-wind scores the highest total score, while solar PV scores the lowest and an agricultural biomass plant is considered unviable altogether. Large scale wind has a middling score, as does cogeneration in the natural gas connected scenario (Scenario 1).

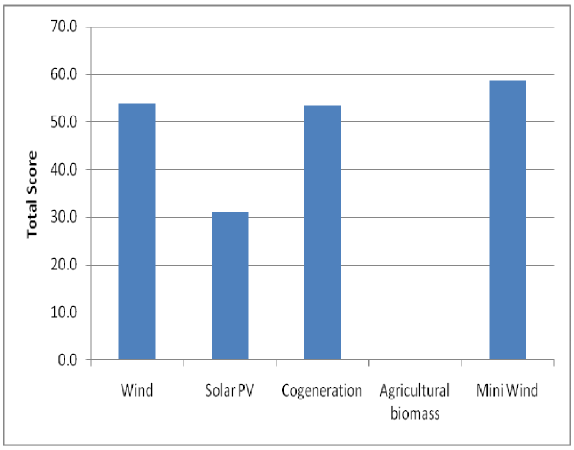


Figure 30: SCEV CEDAT MCDA Results (Scenario 1)

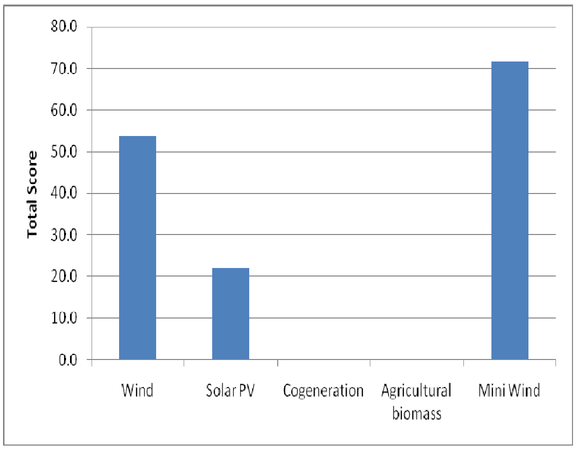


Figure 31: SCEV CEDAT MCDA Results (Scenario 2)

Table 19 details the SCEV case study Scenario 1 results of each of the criteria calculated in CEDAT – emissions abatement and capital and household cost, as well as the total score from the MCDA process and an indication of how much energy each option produces as a percentage of the community's annual energy need.  Table 20 details the technical configuration of each of the options as well as the intermediate cost variables that lead to the results shown in Table 19, Figure 30 and Figure 31.  These tables show that the largest size project proposed by CEDAT is a 0.5MW wind turbine, which also produces the most electricity and abates the most carbon emissions.  While the smallest project is a 40kW cogeneration plant, which abates the least amount of carbon.  The mini-wind project requires 12 turbines, while 233 1kw solar PV systems are required to produce a similar amount of energy.

Of all the options, only the mini-wind and cogeneration options cost less than business as usual.  Solar and large scale wind cost a similar amount per household per year – greater than $950, making them expensive options.  However, if you compare solar PV which has the highest costs (capital and household) despite significant subsidy with cogeneration which has the lowest costs (capital and household) despite no subsidy, this suggests that RECs income does not significantly influence which technologies SCEV should consider.

It is interesting to note that despite having the highest total score, mini-wind does not have the best score in any single criterion, instead it scores consistantly well across all of them.

**Table 19: SCEV CEDAT MCDA Criteria Results (Scenario 1)**

| Technology Option | Emissions Abatement [tCO2e] | Capital Cost [$M] | Annual cost of project per household [$/yr] | Percentage of Community's Energy Needs Met [%] | Total Score |
|---|---|---|---|---|---|
| Wind | 973 | 1.25 | 955 | 374.4% | 53.8 |
| Solar PV | 260 | 1.63 | 1012 | 100.1% | 31.1 |
| Cogeneration | 228 | 0.06 | 154 | 132.6% | 53.3 |
| Agricultural biomass | --- | --- | --- | --- | --- |
| Mini Wind | 274 | 0.44 | 327 | 105.5% | 58.6 |

**Table 20: SCEV CEDAT technical and economic results**

| Technology Option | Project Size [MW] | Generation capacity [MWh/yr] | Number of units | Area require [m2] | Estimated Income from RECs prior to 2012 [$/yr] | Unit cost [c/kWh] | Project cost as a percentage of current household energy cost [%] |
|---|---|---|---|---|---|---|---|
| Wind | 0.5 | 1093.27 | 1 | 78400 | 43731 | 12.73 | 181.6% |
| Solar PV | 0.233 | 292.34 | 233 | 3914 | 41806 | 48.93 | 192.6% |
| Cogeneration | 0.04 | 387.19 | --- | --- | 0 | 3.99 | 29.4% |
| Agricultural biomass | --- | --- | --- | --- | --- | --- | --- |
| Mini Wind | 0.12 | 308.00 | 12 | --- | 19712 | 17.03 | 62.3% |

# 9. DISCUSSION, RECOMMENDATIONS AND CONCLUSION

The purpose of this research has been to create and trial a tool (CEDAT) that can help communities overcome technical knowledge constraints to community energy projects. It was identified that a decision-support tool that provides a preliminary option assessment to target further investigation could be one method of addressing the stated constraint. Once developed CEDAT was applied to a case study of the Sydney Coastal Ecovillage (SCEV) to assess whether it would achieve its intended purpose. This section discusses the results of that case study in terms of CEDAT's ability to generate *useful information*, its usability and the general usefulness of the research process employed for members of the SCEV community. Recommendations are then made firstly regarding ways to improve and expand CEDAT so that it can better assist the removal of technical knowledge barriers and enable community energy projects.

## 9.1.SCEV CASE STUDY RESULTS DISCUSSION

In the context of this research, useful information is a function of relevance and accuracy. Thus, the CEDAT results from the SCEV case study are discussed in light of their relevance for members of SCEV and their accuracy. Because MCDA processes are by their nature subjective, there is no one right answer for the results generated. Also since the SCEV energy project is yet to be built it is impossible to know with certainty the accuracy of the energy, cost and emissions variables calcuated. Instead questions of reasonableness and confidence are considered and where possible the results will be compared to literature values. Before discussing the results of the MCDA process (total score values) the criteria and key underpinning variables are considered.

**Technical configuration**

The technical configurations proposed (Table 20) generally seem reasonable, given the user inputs which are appropriate for a highly energy efficient and energy concious community. For example, the solar PV option equates to a 2.33kW solar system per household. However, the cogeneration option seems small compared to the others – 40kW as opposed to 233kW for solar PV. However, this can be explained by the high capacity factor of the technology and that there are two forms of energy generated – heat and electricity and that the 40kWe nameplate power rating only relates to electricity.

Although the technical configurations produced by CEDAT appear reasonable, beyond providing the basis for all other CEDAT calculations, these results are not particularly relevant for members of SCEV. This is because it is unlikely that the energy project they undertake will utilize only one technology option. However, the relative difference in nameplate power rating across the options does provide a useful indication of the technical potential of each technology for SCEV.

One of the modelling assumptions in CEDAT is that the size of the technologies proposed are based on the community's energy needs and the unit size of an energy technology. The consequence of this modelling process is that CEDAT proposes wind and congeneration configurations for SCEV that produce significantly more energy than the community needs – 374% and 132% respectively. Conversley, solar PV and mini-wind are scalled to produce almost exactly 100% of SCEV's annual energy needs. This is relevant for SCEV given the contentious objective of whether or not to be a net exporter of energy or 100% self sufficient and consider cogeneration as one option for doing this. Another assumption in CEDAT is that projects will be grid connection and this version cannot model energy self-sufficent systems and is thus mainly useful for achieving the first option, although CEDAT results can inform more the more detailed modelling required for the second option. Nevertheless, it is interesting to note that cogeneration is potentially a good technology option for achieving the aim of being a net exporter of energy, given the unit size of a cogeneration plant, while dedicated additional solar pv and mini-wind units would have to be added to export energy.

A positive feature associated with the assumption that projects will be grid connected, is that the question of robustness or resilience of the energy project is not significant. For example, since solar PV is modelled to provide 100.1% of SCEV's energy needs, if the year is particularly cloudy, the amount of energy produced by the project may drop below the community's needs as there is no safety margin. However, in such cases the electricity grid can provide the shortfall. However, the robustness and resilience of community energy systems is an issue that communities should consider and that if CEDAT were to be developed to incorporate non-grid connected options, a modifiable safety factor would have to be explicitly included.

**Capital cost**

There is a large difference in capital cost estimated by CEDAT for the different options, from \$60,000 for a cogeneration plant to \$1.63million for a solar PV farm. The capital cost for cogeneration seems unreasonably low, which suggests a flaw in the base cost data. The figure of \$1.55million/MW used in CEDAT would not apply to a cogeneration plant as small as 40kW, because economies of scale associated with labour and development costs would not be captured by a plant of that size. In future development of CEDAT this flaw needs to be addressed. However, the wind capital cost (\$1.25million for a 0.5MW project) seems reasonable when compared to the Hepburn community wind farm which is developing a wind farm eight times the size (4MW) at approximately eight times the cost (~\$10million) (Hepburn Wind, 2008).

**Annual houshold cost**

It is difficult to determine whether annual household cost of the options proposed are reasonable, as this is not a figure typically considered in the energy supply sector. Instead, unit cost is are discussed as a key underpinning variable. Table 21 compares the unit cost figures generated by CEDAT to literature values of three of the options (mini-wind literature values were unforthcoming).

**Table 21: Comparison of CEDAT unit cost results with literature values for wind, solar PV and cogeneration**

| Technology Option | CEDAT Unit costs | Literature unit Costs | Source |
|---|---|---|---|
| Wind | 12. 73c/kWh | 11c/kWh | Hepburn Wind (2008) |
| Solar PV | 48.93c/kWh | 11-20c/kWh | Diesendorf (2007) |
| Cogeneration | 3.99c/kWh | 4-7c/kWh | RDGWG (2006 in Usher et al, 2008) |

A Comparison between the wind unit cost figures cited in the literature and that calculated by CEDAT suggests, the CEDAT figure is a reasonable result. It is slightly higher than the literature, however, the wind resource at Narara (6.3m/s) and the energy modelling method used would result in lower annual energy production than the literature values. In comparision to wind, the unit cost for mini-wind also seems reasonable, as it is above wind, but not significantly, thereby accounting for the lower efficiency associated with smaller wind turbines. Conversely, the unit Solar PV cost is more than double the upper bound in the literature – 48.9c/kWh compared with 20c/kWh. The cogeneration unit cost given the size of the plant projected (40kW) seems low (~4c/kWh), as it is at the lower bound of the literature values which refer to large gas turbines (RDGWD, 2006 in Usher et al, 2008). This suggests that the modelling processes programed in CEDAT are favourably biased towards cogeneration and unfavourably biased towards solar PV. The reason for this is unclear and as such would be worth further investigation.

**Total Score**

The reasonableness and thus usefulness of the total score values in CEDAT and associated recommendations about technologies that are worth further investigation is based on three factors:

1. The limitations of the scaling algorithm employed;
2. The appropriateness of the criteria used, given the community's objectives; and
3. The quality of the input data.

One of the consequences of using the min-max scaling algorithm is that when an additional option is included in the MCDA there is a reducing the total score range. This can be seen by comparing the results of the two scenarios (Figure 30 and Figure 31). In Scenario 2, which excluded both biomass and cogeneration the range was from ~20-70, while in Scenario 1, which only excluded biomass the range diminished to ~30-60. The explanation for this is that the min-max scaling algorithm considers the relative difference between the options for each criteria, thus the effect of adding more options reduces the relative difference, reducing the range. To reduce the relativity of this process, users could set absolute upper and lower bounds for each criterion – the ranges scaling approach.

Regarding the second factor affecting the MCDA CEDAT results, since the criteria were agreed to by participants at the SCEV workshop, it is assumed that they are appropriate. For the issue of input data quality, specific analysis of the energy use and generation model as well as the cost criteria have already been discussed in this section. The remaining data issues are examined in light of the result generated.

The SCEV MCDA results indicated that mini-wind is the option most worth further investigation for the SCEV energy project. This result was a surprise to a number of the workshop participants. This was because they had hypothesized that solar PV would likely be the best technology option for SCEV as the location is a "sun-trap" (Male 3) and that wind would not be particularly viable as it is in a valley. However, the CEDAT results for Scenario 2 indicate that solar PV is not a particularly favourable option (weighted total score of 22.2/100), while mini-wind was the most favourable option (weighted total score of 71.6/100) and large-scale wind also scoring significantly higher than solar PV (weighted total score of 53.4/100). There are a number of factors that could account for the difference between the CEDAT results and the initial predictions.

Firstly, wind data used from the Renewable Energy Atlas, does not account for location specific information, such as the fact that the site is in a valley and surrounded by trees, which increases wind-shear, thus decreasing wind speed. However, on further investigation it was discovered that the local Bureau of Meteorology weather recording station, which would have been the basis for the local weather data, is located at the proposed SCEV site on Research Rd, Narara. The wind assessment for the area is therefore likely to be accurate.

Secondly, large-scale wind scores particularly well due to its large emission abatement potential of 973tonnes $CO_2$e compared with only 260 tonnes $CO_2$e in the PV option. This is due to the fact that the emissions assessment in CEDAT relates directly to energy generated. This modelling technique unfairly favours options that produce more energy, with the exception of cogeneration as it has an emissions factor greater than zero. As such, given large scale wind produces 374% of the community's energy needs, it will by default save more emissions. However, given that the community wants to be an exporter of low carbon energy this may be a positive consideration instead of a negative one.

Finally, solar PV is an expensive technology, the most expensive of all options considered in CEDAT (Table 9). Thus, in a MCDA process that considers two economic indicators, it is hard for solar PV to score highly. Solar PV as identified in Section 6.3.4, has many benefits, including its modularity and ease of use and that it generates electricity at times of peak demand. Of these the complexity criteria attempts to incorporate the benefits of modularity and ease of use, which results in solar PV scoring 100/100 (Table 17). However, the benefit of generating energy at times of peak demand is not considered, but could be incorporated as part of a costing analysis and additional MCDA criteria in a future version of CEDAT.

It is also interesting to note that mini-wind may have even greater potential than estimated in CEDAT, as the modelling equation applied, typically underestimates energy generation potential (Section 7.2.1). Having considered all the factors discussed I conclude that given the economic realities of solar PV, mini-wind has a greater potential as an energy source at Narara than members of the SCEV anticipated. Additionally, it is clear that agricultural bioenergy is not worth considering beyond very small niche applications due to the lack of resource availability. Based on these conclusions, I suggest that CEDAT has produced useful information that is highly relevant for SCEV and sufficiently accurate for its intended purpose.

However, to have more confidence in the results generated an uncertainty analysis and sensitivity analyses could be undertaken. Specifically, a sensitivity analysis could test the significance of:

- Wind speed in generating the wind and mini-wind outputs and particularly weighted total score
- Solar insolation in generating the solar PV outputs and particularly weighted total score
- Cost input data (Table 9) in generating the different weighted total scores for each option
- Size of subsidy available in generating annual cost of project per household
- Criteria weightings in generating the MCDA results.

## 9.2. USABILITY AND USEFULNESS OF CEDAT DISCUSSION

Although there were many sound reasons for applying CEDAT to a case study of SCEV, issues became apparent during the research process which indicated that a tool like CEDAT was not expressly what the SCEV energy project needed. One indicator was that the level of technical experience in the project team was such that technical knowledge constraints were not the most significant barrier facing this community. Instead time, differentiated knowledge levels and the need for someone to take on a project management role (Boo, 2009) came across as the key constraints. Additionally, the design of CEDAT involved making assumptions that run counter to the needs of SCEV. For example Section 7.1 explicitly states that CEDAT does not model technologies that match to particular energy loads, as the process is too complex. However, having technologies that match particular energy loads is one of the main objectives of SCEV, and thus one of its main requirements for a useful options analysis. If CEDAT is developed further, this assumption should be revisited.

The imperfect fit of my prototype model and the SCEV community's needs, meant that the research methodology had limitations. For example, despite sending the model out for further feedback very little was forthcoming. Another key limiting factor was time. Ideally, the research process would have included an additional workshop to gain further information and feedback. This would have provided more informed discussion regarding which energy options to further pursue both for SCEV specifically as well as the usefulness of CEDAT more generally.

Nevertheless, despite these methodological limitations feedback was provided about the usefulness of CEDAT at the end of the workshop and much of it was positive. Specifically, CEDAT was called an "interesting, educational tool" (Female 1) that in combination with the workshop was useful for initiating discussion. Particularly, it enabled the identification of key questions that must be resolved by the group e.g., the role of baseload energy (Male 2). One workshop participant did question CEDAT's usefulness due to lack of detail associated with each of the options (Female 3). However, the same participant also indicated that once the technological summary sheets were further developed (which has since occurred) CEDAT would provide a useful starting point to find out about multiple sustainable energy technology options, as most resources she had seen focus on just one. CEDAT was also praised as being able to move the discussion about sustainable energy from the realm of ideas to the practical – this is what it might cost, how many turbines we might need etc (Male 3). Additionally, the results of the SCEV CEDAT case study will form the basis for a further research report to SCEV.

Given this feedback and despite the limitations associated with both CEDAT and the case study methodology, CEDAT has fulfilled its research and design brief. It provided a framework for SCEV members to better understand some of the low carbon technology options suitable for SCEV and has targeted items for further investigation, by providing the basis for my research report to SCEV which will include more information about mini-wind options. An unforseen additional function of CEDAT is that when combined with a well facilitated workshop it can provide a useful discussion and planning framework for groups. While it is possible to conclude that CEDAT was useful for SCEV, the case-study research method employed does not enable a comprehensive answer to the question of whether CEDAT was useful for reducing technical knowledge barriers facing the SCEV community. Thus, any future research applying CEDAT to a community should explicitly address this question.

## 9.3. RECOMMENDATIONS FOR EXTENDING CEDAT

The Community Energy Decision Assistance Tool (CEDAT) is a completely new tool, developed as part of this research. The discussion from Section 9.2 identifies that CEDAT in its current form is useful. However, it could be even more useful for community energy proponents if it and the accompanying research methodology were further developed. This section outlines recommendations for extending CEDAT, its application and outlines some of the data required.

**Include temporal modelling in CEDAT**

Currently, annual averages are used for input data. Using monthly averages or more detailed averages for wind, solar and energy use would significantly increase the accuracy of the outputs. Particularly, a temporal approach will give a better indication of network cost as network infrastructure is required for the maximum not the average. This would require having publicly accessible average *monthly* wind velocity data for locations across Australia that could be incorporated into the Renewable Energy atlas.

**Increase the sophistication of the energy use model**

Specifically, this could be done by considering the community's peak energy use – winter and summer as well as annual energy needs. This would require information pertaining to either typical peak energy use data for communities of specific sizes or residential peak use data.

**Incorporate more technology options**

Other technology options appropriate to the community scale that could be incorporated into CEDAT include:

- Micro and mini hydro
- Solar thermal
- Ground source heat pumps
- Hydrogen fuel cells
- Batteries and other energy storage options

**Increase the sophistication of energy generation modelling for each technology**

For biomass incorporate a more sophisticated analysis of energy available from different biomass sources, instead of assuming a standard energy conversion factor of 0.8 MWh of energy for every wet tonne of biomass. For both wind options, take a wind engineering modelling approach, which is possible if temporal modelling is incorporated into CEDAT and the Weibull k parameter is known.

**Include the function to resize the wind and mini-wind options**

Currently, the solar PV, biomass and cogeneration options can be resized by users based on more detailed site specific information. This function should be extended to the remaining two options.

**Include technology bundling options**

Currently, technologies are modelled in isolation, such that one technology meets a community's annual energy needs. However, with an increase in sophistication of the modelling in CEDAT it will become possible to incorporate multiple technologies into one option or scenario.

**Include energy self sufficiency/grid independent options in CEDAT**
Currently, it is assumed that energy projects modelled in CEDAT are connected to the grid. However, there are many communities that may wish to become completely energy self-sufficient. When CEDAT is updated to incorporate temporal modelling, technology bundling options, energy storage options and peak energy use, CEDAT should incorporate energy self-sufficiency options.

**Incorporate energy efficiency options into CEDAT**
One mechanism for doing this would be to bundle energy efficiency measures such as installing insulation, with cogeneration and PV generation options as they incorporate building work/retrofitting at point of use.

**Make CEDAT responsive to likely gains in energy efficiency (thus reduction in energy use)**
Currently 2005 household energy data is used as one mechanism of calculating community energy use. It is likely that there will be advances in residential energy efficiency, for example in NSW associated with BASIX that should be considered in future versions of CEDAT.

**Increase the sophistication of the environmental analysis**
Instead of using point of generation emissions factors, lifecycle emissions factors for each technology should be used. Additionally, other environmental indicators should be considered and calculated, for example lifecycle water use.

**Increase the sophistication of the economic analysis**
This could include incorporating:

- Cost curves for technologies based on a range of sizes, which is particularly relevant for biomass and cogeneration options;
- A cost analysis of the likely impact of the sale of electricity from community energy projects at times of peak energy demand;
- Additional cost factors relevant to community energy projects, such as initial development costs; and
- Temporal cost curves and analysis, considering how costs of technologies and of the Australian energy supply will change over time.

**Expand the subsidy analysis in CEDAT**
Currently, the subsidy analysis in CEDAT only considers the impact of the Renewable Energy Target, this analysis should be expanded to include existing state based solar feed-in tariffs and the impact of other potential energy policies in Australia for example a federal feed-in

tariff similar to the German Renewable Energy Law that sets different tariffs for different technologies.

**Increase the sophistication of the MCDA process**
This could be done by providing an option whereby CEDAT users can specify maximum and minimum values for each of the criteria in the MCDA and thus apply the Ranges scaling algorithm instead of the Min-Max method.

**Include inputs and outputs related to different community energy project functions or institutional arrangements.**
CEDAT is currently of most use for existing communities that wish to start an energy project such as the Hepburn Community Wind Farm, but are not aware of the most appropriate technology. However, there are a number of different functions that community energy projects can fulfil and institutional forms they can take, for example:

- Grid connected project managed by a co-op, trust or company
- Small environmentally minded community looking to be energy self-sufficient
- Larger community or council area, looking to set up a sophisticated distributed energy approach – small utility
- Providing input options for these different community energy project functions and forms would significantly increase the applicability of CEDAT in Australia.

**Incorporate an uncertainty analysis into CEDAT**
An uncertainty analysis would give CEDAT users an indication of the level of error in the results in CEDAT as a way to build the confidence they can have in the results.

**Develop into a web tool**
Despite the intention that CEDAT become a used tool, it is currently limited to users with access to Excel 2007 and is not available for public download. One way of making CEDAT even more accessible would be to turn it into a web based tool.

**Develop a comprehensive social research methodology**
This process would involve an action research process trialling CEDAT with a number of communities. The purpose of which would be to further inform the development of CEDAT and other potentially useful tools and processes, as well as providing expert support for the development of community energy projects in Australia

**Maintain the user friendly interface**
A key design parameter in CEDAT is that it be accessible to communities without extensive technical knowledge or access to sophisticated site specific data. This function of CEDAT should be maintained through its further development; otherwise it will become too similar to existing energy models such as HOMER and will not fulfil its designed purpose. As such,

to simultaneously increase the sophistication of the energy modelling in CEDAT and maintain its accessibility, a number of data gaps must be filled. These data gaps include:

- Biomass availability at sites across Australia, although a recent biomass appraisal has been undertaken and the Renewable Energy Atlas includes broad land use categories, neither has sufficiently specific information for use in a tool such as CEDAT.
- Solar thermal calculations data, which relate energy generation potential to solar insolation
- Water energy resources, specifically energy potential of different rivers, streams and dams or an easy methodology for communities to approximate, these numbers.
- Peak energy use data for communities or residences.

If these data sets are determined and/or made publicly available, they would not only increase the usefulness of CEDAT, but would generally assist the development of community energy projects.

## 9.4. CONCLUSION

In conclusion, this research is an important contribution to the development of the fledgling community energy sector in Australia. Specifically, the Community Energy Decision Assistance Tool (CEDAT) has the ability to support communities by addressing the significant barrier of technical knowledge constraints. CEDAT brings together:

- An analysis of the needs of community energy proponents in responding to technical knowledge constraints;
- Multi-criteria decision analysis (MCDA) frameworks; and
- Energy modelling techniques for five community scale sustainable energy technologies.

One of the core elements of community energy is the meaningful participation of a diverse range of people in the development of projects (Walker and Cass, 2007). However, despite the complexity associated with energy systems and the multiple competing objectives communities' face, MCDA processes have traditionally not been applied to the community energy sector. As such, from a review of energy models, community energy resources and a 'barrier benefit analysis' it was clear that there was a manifest need for a tool such as CEDAT. Specifically, the decision support element of CEDAT provides a mechanism for synthesising technical, economic and environmental data into an accessible framework for facilitated discussion.

A key aim of the research was that the tool created be useable. Thus it was important to maximise the accessibility and usefulness of CEDAT for a range of community energy proponents. This was done by consulting with community energy professionals, considering the range of CEDAT users' knowledge and needs in the model development and by undertaking a case study.  The accessibility of the tool was established particularly through the application of CEDAT to the Sydney Coastal Ecovillage (SCEV), where a people from energy professionals to retirees were able to make use of it.

The case study also showed that CEDAT was useful.  Based on the results generated, mini-wind is now the target of further investigation for the SCEV site at Narara. Although, it should be noted that there were limits to CEDAT's usefulness for SCEV; for example the inability of CEDAT to match energy supply and demand loads was a drawback. Nevertheless, with further development the limitations of CEDAT could be addressed.

Key areas of further research identified specifically related to the area of overcoming technical knowledge barriers are:

1. Expand and develop CEDAT further, specifically increase the sophistication and accuracy of CEDAT by incorporating more technology options and scenarios, temporal modelling and ranges approaches to MCDA;
2. Increase the breadth and depth of publicly available renewable energy resource and modelling data by expanding the scope of the *Australian Renewable Energy Atlas* (DEWHA, 2009);
3. Undertake further research into the needs of community energy proponents, by trialling CEDAT and other support tools with a wide range of different community energy projects across Australia.

In addition to the creation of CEDAT, this research undertook a holistic analysis of the barriers to and benefits of community energy in the Australian context.  It established that community energy projects have a significant role to play in increasing the sustainability of Australia's energy system.  The analysis also provides a targeted basis for research to support the establishment of community energy projects in Australia.

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# APPENDIX A – REVIEW OF SOLAR THERMAL POWER TECHNOLOGIES

## A.1 DESCRIPTION

Solar thermal technologies work on the premise of converting sunlight into thermal energy or heat that can be either used to provide heating services or to generate electricity. Solar insolation is the most abundant energy source available to us. Existing solar thermal technologies (as distinct from solar PV technologies which were discussed in Section 6.3) range from passive solar building design to household scale water heating systems to 100s of megawatt power stations. In this section solar thermal power station technologies will be discussed. Household scale solar hot water and space heating systems will not be discussed as already stated.

As shown in Figure 32, currently there are four main concentrating solar thermal power technologies (Mills, 2004 in Romero-Alvarez and Zarza, 2007; Lovegrove and Dennis, 2006; Diesendorf, 2007): parabolic trough collectors, linear Fresnel reflector systems, power towers or central receiver systems and dish/engine systems.

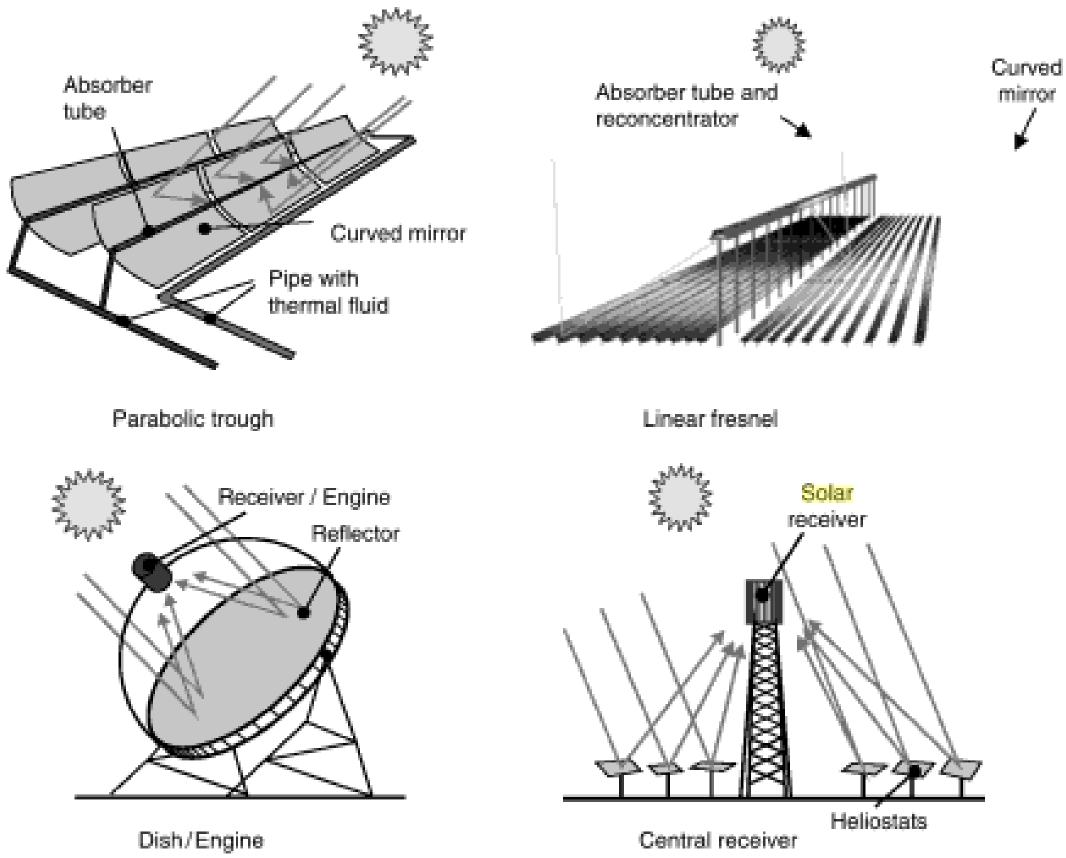



**Figure 32: Schematic diagrams of the four concentrating solar thermal power systems scaled up to pilot and demonstration sizes (Romero-Alvarez and Zarza, 2007)**

Parabolic trough collectors and linear Fresnel reflector systems are two dimensional concentrating systems, which focus solar radiation onto a receiving tube in the focal line of the one-axis tracking mirrors (Romero-Alvarez and Zarza, 2007). From there the concentrated radiation heats the fluid in the receiver tube and the fluid circulates, transforming solar radiation into sensible heat of the fluid (ibid).

Power towers have large two-axis heliostat fields (individual fixed focus dish units) that focus solar radiation on solar receivers located on top of a tower. The solar receivers transfer energy to a thermal fluid. From there the fluid is used to convert heat into electricity in a similar operating system to a fossil fuel power station (ibid).

Dish/engine systems such as the 'Big Dish' developed at ANU, are individual parabolic dishes that track the sun on two axes. The concentrating dishes focus the solar radiation at a focal point which houses a boiler generating steam which can be pumped to a nearby generator or energy storage system.

All literature reviewed states that concentrating solar thermal systems will be most attractive if combined with heat storage technologies (Romero-Alvarez and Zarza, 2007; Lovegrove and Dennis, 2006; Diesendorf, 2007). There are a number of heat storage technologies available and in commercialization.

## A.2 TECHNICAL CONSIDERATIONS

There are a number of key technical considerations for solar thermal systems, these include, scale, efficiency, annual capacity factor, siting/location considerations. Table 23 compares the efficiencies and scales of the different technologies available. This shows that although they are the smallest systems dish/engine systems also have the greatest efficiencies. However, it also shows that solar thermal systems are less efficient in converting solar insolation into electricity than wind turbines are at converting wind energy into electricity.

There are a number of considerations when finding an appropriate site for solar thermal power station, these include:

- A minimum yearly direct insolation of 2000kwh/m² (IEA, 2008), which is more an economic consideration than a technical constraint, as solar thermal power stations still operate at less than 2000kwh/m², they will simply produce less energy and thus may not be worth the investment;
- Location – specifically solar thermal power stations work best in rural, dry climatic zones where there is clear air rather than in cities and moist costal zones where there is more scattering of sunlight (Diesendorf, 2007);
- Site should have no shading;
- Space requirements, which vary for different technologies;
- Proximity to either load or transmission or distribution to minimize cost and transmission losses. Large solar thermal power stations connect directly into the

high voltage transmission lines, while dish/engine systems can connect into the distribution system or can be used to power off-grid facilities.

**Table 22: Characteristics of concentrating solar power systems (DeMeo and Galdo, 1997; Tyneret al, 2000 in Romero-Alvarez and Zarza, 2007)**

| System | Peak Efficiency (%) | Annual Efficiency (%) | Annual Capacity Factor (%) | System size (MW) | Temp (°C) | Concentration ratio |
|---|---|---|---|---|---|---|
| Trough collectors/linear Fresnel | 21 | 14-18(p) | 24 (d) | 30-80 | 260-400 | 8-80 |
| Power tower | 23 | 14-19(p) | 25-70(p) | 10-200 | 300-1000 | 600-1000 |
| Dish/engine | 29 | 18-23(p) | 25(p) | 5-25kW | 500-1200 | 800-8000 |

(d) = demonstrated, (p) = projected, based on pilot-scale testing. Annual capacity factor refers to the fraction of the year the technological can deliver solar energy at rated power.

**Siting considerations**

Once a site is chosen in addition to the technical considerations described additional design factors to be considered for the individual systems include collector orientation, ambient air temperature, working fluid and fluid flow rate, solar collector soiling factor.

**Energy generation**

The basic concept behind active solar thermal power station is that concentrated sunlight heats water (or some other fluid) to sufficiently high temperatures to turn a steam turbine or heat engine and hence generate electricity as shown in Figure 33. However, despite available schematics there is little information available in the public domain that could be used as the basis for a simple energy generation model, linking energy generation potential to locational inputs such as average daily solar insolation. The energy modelling equations that are available (Romero-Alvarez and Zarza, 2007) are highly complex and require specialist knowledge beyond that available to this research project.

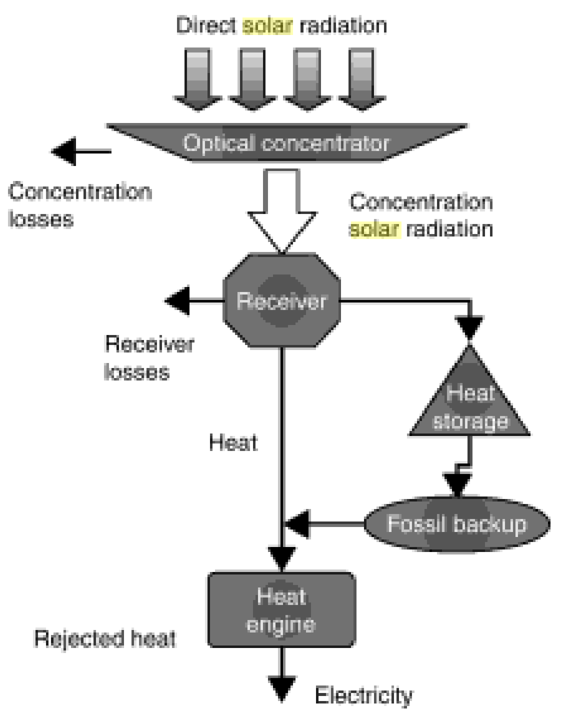



**Figure 33 Flow diagram for a typical solar thermal power plant (Romero-Alvarez and Zarza, 2007)**

## A.3 COST

The cost of solar thermal power stations is high. Romero-Alvarez and Zarza, (2007) give current unit costs for large scale trough and power tower systems at US$ 0.15-0.18/kWh. While Lovegrove et al (2004 in Diesendorf 2007), estimates current unit costs for paraboloidal dish systems at about AU$0.15-0.16/kWh. However, SolarPACES (2006, in Lovegrove and Dennis 2006) project that for large scale systems costs could fall as low as US$ 0.035-0.063/kWh by 2020, which is comparable with wind.

Nevertheless, one of the biggest barriers to solar thermal is the high capital investment required. Project cost comparative capital and O&M costs for solar thermal power stations using trough technology in Australia are given in Table 24.

**Table 23: Costs of Concentrating Solar Thermal technology**

| Source | Size (MW) | Capital cost ($/kW) | Fixed O&M costs ($/kW/year) | Variable O&M costs ($/MWh) |
|---|---|---|---|---|
| SEDA (2002) | --- | 3000 | --- | 5 |
| Access Economics (2009) | --- | 5000 | 70 | 1.09 |
| MMA (2007) | 100 | 3200 | 50 | --- |

Geyer (2002 in Romero-Alvarez and Zarza, 2007) estimates the capital cost for dish systems to be about double those given in Table X. This represents a problem for securing investment as payback periods will be longer, particularly when power station lifetimes are given at 25 years.

## A.4 BARRIERS & BENEFITS

Barriers to solar thermal power systems include:

- High initial investment costs ($US3000-4000/kW), which is a problem faced by many renewable energy technologies, as all the capital is required upfront. Generally fuel costs are free and maintenance costs are generally low, but since they are emerging technologies, economies of scale for parts and equipment have not been reached (Romero-Alvarez and Zarza, 2007);
- Lack of appropriate power purchase agreements (ibid);

Conversely, the advantages of concentrating solar thermal power include (Morse, 2000 in Romero-Alvarez and Zarza, 2007):

- Proven capabilities;
- Restricted modularity (ibid);
- Can be rapidly deployed;
- Technological and financial risks expected to be low (Romero-Alvarez and Zarza, 2007);
- Concentrating solar thermal systems have the ability to substitute for coal and nuclear sources of heat and continue to utilize standard turbine generator technology;
- Offers the potential for power on demand or continuous solar-only generation e.g. by using stored heat in various forms (IEA, 2008); and
- Peak production of electricity usually matches peaks in electricity demand.

One contested feature in the literature is the ability of solar thermal power stations to decentralise energy supply. Typically solar thermal power projects are planned in the 15-100MW range (NREL, 2003). Although 15MW is significantly smaller than large centralised fossil fuel power plants, it is at the upper limit of what is likely to be economically viable for a community, particularly given high capital cost. So while dish systems particularly are modular, scalability is restricted economically (although likely not technically) due to their expensive thermodynamic cycle.

## A.5 SOLAR THERMAL INDUSTRY AND COMMUNITY ENERGY APPLICATION

The solar thermal industry saw growth in the US, particularly California in the 80s, due to the oil price shocks and the prohibitive energy pricing. However, during the 90s as energy prices went down, little was done to expand the solar thermal industry globally. In the last 5 years this industry has had resurgence, particularly in Spain and California. As such, the technologies outlined are at various stages of commercialization. Trough technology has the longest track record, with 354 $MW_e$ of installed capacity in California, operating continuously for over 20 years (Lovegrove and Dennis, 2006). Currently, a number of large-scale demonstration solar tower systems are being established in Spain, while dish/engine systems are being trialled particularly in remote or off-grid locations around the world.
In Australia, a number of world class solar thermal research and development (R&D) institutes are continuing to develop cutting edge solar thermal technologies. However, a lack of government support to date and internationally uncompetitive market signals, have meant that many of these technologies and associated start-up companies have gone overseas for commercialisation and deployment.

To date, there are no known community energy solar thermal projects as they are defined in this research. However, a 3MW power tower and energy storage system is under development by the company Lloyd Energy Systems to provide energy to the community of Lake Cargelligo in western NSW. In addition, it is likely that dish/engine systems could also be used for community energy purposes. The rational for this is their scale and modularity and with advances in energy storage ability to provide 100% of a community's energy needs. Indeed, Becker et al (2002 in Romero-Alvarez and Zarza, 2007), suggest they have a niche market in distributed on-grid and remote/off-grid power applications. However, high capital investment required for solar thermal particularly dish/engine systems means that any application is likely to be small, until costs are brought down or good investment arrangements for communities are developed.

# APPENDIX B: CEDAT MODEL SCREENSHOTS AND CD

CEDAT has 15 tabs, screenshots of most of these tabs are provided to give an overview of how CEDAT functions. A screenshot has not been provided of the Australian Energy and Emissions Data as tables of all the information included are provided in Section 7 of this thesis. A screenshot of the Reference tab is also not included.

## A.1 INTRODUCTION TAB

### Introduction, Overview and Users Guide to the Community Energy Decision Assistance Tool (CEDAT)

Start

#### Purpose

The purpose of CEDAT is to provide community groups interested in developing a community scale energy project with a framework for better understanding low carbon technology options suitable for their community and to target further investigation. The analysis is based on the aims of the project and information related to the location of the community. CEDAT also provides preliminary economic, environmental and technical information for each of the technologies.

#### How to use CEDAT

Note: CEDAT is best used as part of a broader sustainability decision making process, about the nature of your community energy project. It is suggested that you undertake the first two phases of this broader process (details below) before using CEDAT.

Step 1. Enable macros and follow the prompts by clicking the buttons throughout this model. Please note, macros only work on PCs, if you are using an Apple, it is possible to use CEDAT, you will have to follow the instructions in each page more carefully.

Step 2. Once you have read the introduction page proceed to the User Input Interface. The User Input Interface includes 3 main sections – energy use, community climate data and siting considerations and criteria.

Step 3. Follow the instructions given in the User Input Interface.

Step 4. Click the Results button to proceed to the Outputs Interface. Follow the instructions given.
Note: brief descriptions of the processes used in CEDAT are detailed at the top of the respective tabs in this model.

#### Community Energy – Sustainability Decision Making Process

CEDAT is best utilized as part of a four-step sustainability decision making process to determine which technology/ies would be appropriate for a community energy project:

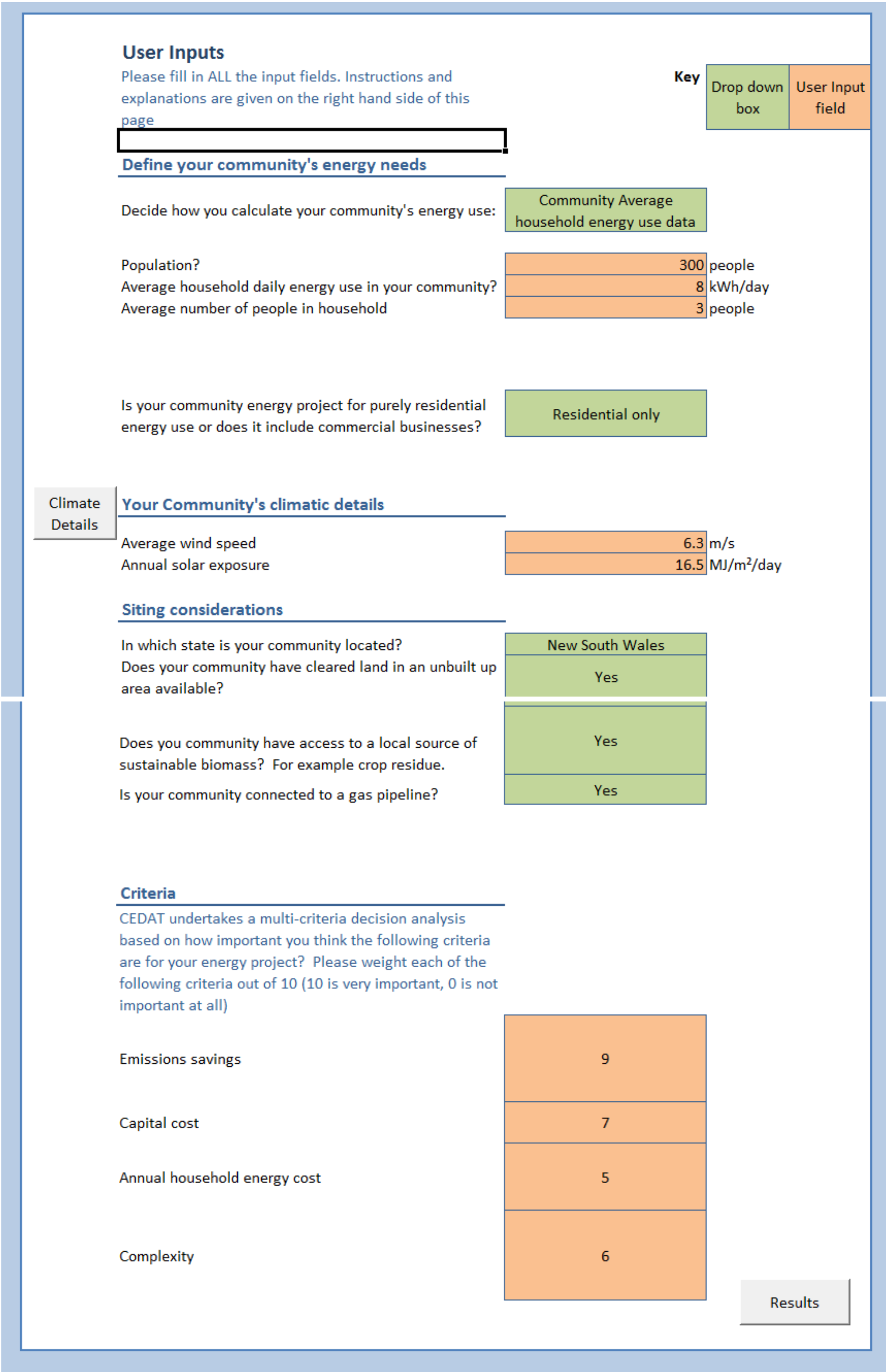
Phase 1: Define the objectives of your community energy project, this includes considering the context of your community and determining why you are undertaking a community energy project.

Phase 2: Define criteria or indicators that can be used to assess different project options given your objectives. In CEDAT four criteria or indicators are programmed into the tool, they are: emissions abatement, capital cost, annual household cost of project and complexity of the technology option.

Step 3: Develop an options assessment. This includes creating a list of options that could fulfil your objectives and undertaking an analysis of each of the options based on the criteria you have developed. The primary purpose of CEDAT is to undertake this options assessment. It does this by calculating information relating to the four indicators above and a number of other technical and economic indicators for five technology options that may or may not be possible options for your community.

Step 4: Determine the most appropriate option/options to pursue. This is done by applying a multi-criteria decision analysis (MCDA) to a matrix of the criteria and technology options, based on information relating to the objectives and context of your community energy project. In CEDAT a graph and table of total score, which are a result of the MCDA are given in the outputs page, indicating which technology option is likely to be most appropriate and thus worth further investigation for your community (the closer to 100 the score, the more appropriate the technology).

## A.2 USER INPUT INTERFACE



### User Inputs

Please fill in ALL the input fields. Instructions and explanations are given on the right hand side of this page

| Key | Drop down box | User Input field |
|---|---|---|

**Define your community's energy needs**

| | | |
|---|---|---|
| Decide how you calculate your community's energy use: | Community Average household energy use data | |
| Population? | 300 | people |
| Average household daily energy use in your community? | 8 | kWh/day |
| Average number of people in household | 3 | people |
| Is your community energy project for purely residential energy use or does it include commercial businesses? | Residential only | |

Climate Details

**Your Community's climatic details**

| | | |
|---|---|---|
| Average wind speed | 6.3 | m/s |
| Annual solar exposure | 16.5 | $MJ/m^2/day$ |

**Siting considerations**

| | |
|---|---|
| In which state is your community located? | New South Wales |
| Does your community have cleared land in an unbuilt up area available? | Yes |
| Does you community have access to a local source of sustainable biomass? For example crop residue. | Yes |
| Is your community connected to a gas pipeline? | Yes |

**Criteria**

CEDAT undertakes a multi-criteria decision analysis based on how important you think the following criteria are for your energy project? Please weight each of the following criteria out of 10 (10 is very important, 0 is not important at all)

| | |
|---|---|
| Emissions savings | 9 |
| Capital cost | 7 |
| Annual household energy cost | 5 |
| Complexity | 6 |

Results

## A.3 OUTPUT INTERFACE

### Outputs

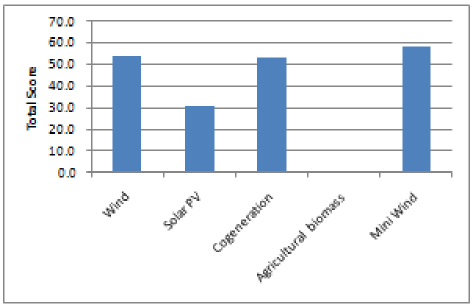
| Enter data to re-size options | Technology Option | Complexity (100=simple, 0=complex | Emission Abatement [tCO2e] | Capital Cost [$M] | Annual household cost [$/yr] | % of Community's Energy Needs Met | Total Score | |
|---|---|---|---|---|---|---|---|---|
| | Wind | 60 | 973 | 1.25 | 955 | 374.4% | 53.8 | Wind summary |
| No | Solar PV | 100 | 260 | 1.63 | 1012 | 100.1% | 31.1 | PV summary |
| No | Cogeneration | 40 | 228 | 0.06 | 154 | 132.6% | 53.3 | Cogen summary |
| Yes | Agricultural biomass | 30 | --- | --- | --- | --- | --- | Biomass summary |
| | Mini Wind | 80 | 274 | 0.44 | 327 | 105.5% | 58.6 | Mini-wind summary |

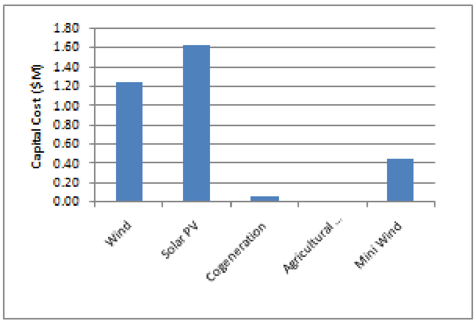
☑ Useful Technical Information

| Technology Option | Project Size [MW] | Generation capacity [MWh/yr] | Number of units | Area required [m2] |
|---|---|---|---|---|
| Wind | 0.5 | 1093.27 | 1 | 78400 |
| Solar PV | 0.233 | 292.34 | 233 | 3914.4 |
| Cogeneration | 0.04 | 387.19 | --- | --- |
| Agricultural biomass | --- | --- | --- | --- |
| Mini Wind | 0.12 | 308.00 | 12 | --- |

☑ Useful Economic Information

| Technology Option | Annual Cost of the project [$/yr] | Estimated Income from RECs prior to 2012 [$/yr] | Annual cost of project incorporating RECs [$/yr] | Unit cost [$/MWh] | as a percentage of current household energy cost % |
|---|---|---|---|---|---|
| Wind | 139183 | 43731 | 95452 | 127.31 | 181.6% |
| Solar PV | 143038 | 41806 | 101232 | 489.28 | 192.6% |
| Cogeneration | 15446 | 0 | 15446 | 39.89 | 29.4% |
| Agricultural | --- | --- | --- | --- | --- |
| Mini Wind | 52435 | 19712 | 32723 | 170.25 | 62.3% |



## A.4 SIZING INTERFACE

### Sizing technological inputs

This page gives you the option to re-size three of the technologies based on more detailed resource availability information. Specifically, annual biomass availability, north facing, unshaded roof area or land available for solar panels and whether your community wants to meet its heating and cooling requirements from cogeneration and export electricity. Please fill in as many of the options as you would like, then return to the outputs page. Once there choose "Yes" from the drop-down list on the left hand side of the technologies you wish to resize based on the information in this tab.

**Biomass**

| | | |
|---|---|---|
| Tonnes of sustainable biomass available per year | 10 | tonnes |

**Solar**

| | | |
|---|---|---|
| Area of north facing unshaded space available in your community | 0 | $m^2$ |

**Cogeneration**

| | |
|---|---|
| Meet heat requirement of your community from cogen and export electricity? | Yes |

Return to Outputs Page

## A.5 ENERGY USE MODEL CALCULATIONS

### Energy Use

**Description:** This tab is the energy use model, specifically the calculations for annual energy use based on the three input options in the User Input Interface. Additionally, number of households in your community is estimated, as one component of calculating average cost of the project per household.

**Option 1- state averages**

| | |
|---|---|
| Residential Energy Use | 1276.92 MWh/y |
| Residential and Commercial Energy Use | 2861.669 MWh/y |
| Energy Use | 1276.92 MWh/y |

**Option 2 - community household data**

| | |
|---|---|
| Residential Energy Use | 292 MWh/y |
| Residential and Commercial Energy Use | 654.3929 MWh/y |
| Energy Use | 292 MWh/y |

**Option 3 - community energy data**

| | |
|---|---|
| Energy Use | 0 MWh/y |

| | |
|---|---|
| **Final Community Energy Use** | **292 MWh/y** |

## A.6 BUSINESS AS USUAL COST CALCULATIONS

### Cost of business as usual

**Description:** This tab includes calculations as to the business as usual cost of energy for your community. Specifically, it calculates the cost of energy for your community if you were to continue purchasing grid electricity. These calculations are based on the energy use model and data in the Aus Energy and Emissions Data tab. This costing analysis is used to compare the cost of each technology project with business as usual.

**2009 Costings**

**Option 1- state averages**

| | |
|---|---|
| Cost of electricity if just electricity and wood | 45727.2 ($/yr) |
| Cost of wood if just electricity and wood | 12640.7 ($/yr) |
| Cost of energy if just electricity and wood | 58367.9 ($/yr) |

| | |
|---|---|
| Cost of wood if gas, elec and wood | 12640.7 ($/yr) |
| Cost of electricity if gas, elec and wood | 35215.2 ($/yr) |
| Cost of gas if gas, elec and wood | 3595.1 ($/yr) |
| Cost of energy if electricity, wood and gas | 51451 ($/yr) |

| | |
|---|---|
| Option 1 cost of energy | 51451 ($/yr) |

**Option 2 - community specific data**

| | |
|---|---|
| Cost of electricity | 52560 ($/yr) |

| | |
|---|---|
| **Final cost of energy per household** | 525.6 ($/yr) |

# A.7 WIND CALCULATIONS

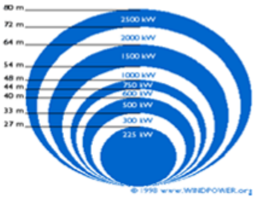
## Wind Calculations

The wind data tab stores many of the assumptions and calculations used to estimate the amount of energy generated and specific size a wind energy project (not mini-wind). It includes assumptions about the power density available in the wind for different average wind speeds. Using the specified average wind speed in your community and this power density data, the energy produced from different turbine configurations (size and number) is calculated.

**Swept area for different turbine sizes**

| Turbine size (k | Rotor Diameter (m | Swept Area (m² |
|---|---|---|
| 2500 | 80 | 5026.548246 |
| 2000 | 72 | 4071.504079 |
| 1500 | 64 | 3216.990877 |
| 1000 | 54 | 2290.221044 |
| 750 | 48 | 1809.557368 |
| 600 | 44 | 1520.530844 |
| 500 | 40 | 1256.637061 |
| 300 | 33 | 855.2985999 |

**Source:** Windpower.org, 1998




**Assumptions:**

| Spacing (Diameters) | Footprint (m2) per turbine | Minimum average wind speed (m/s) |
|---|---|---|
| 7 | 1416.401 | 4.5 |

**Source:** NREL

**Estimated Annual Specific Yield at Hub Height Average Wind Speed**

| Average annual wind speed (m/s) | Air Density (W/m²) | Power Conversion Efficiency | Total Yield (kWh/m²/yr) | Average annual output (MWh/ | Average annual output (MWh/yr)2 | Average annual output (MWh/yr)3 | Average annual output (MWh/yr)5 | Average annual output (MWh/yr) | Average annual output (MWh/yr)6 | Average annual output (MWh/yr)8 | Average annual output (MWh/yr)7 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2500 kW Turbine | 2000 KW Turbine | 1500 KW Turbine | 1000 KW Turbine | 750 KW Turbine | 600 KW Turbine | 500 KW Turbine | 300 KW Turbine |
| 4.0 | 75 | 0.350 | 230 | 1156.1 | 936.4 | 739.9 | 526.8 | 416.2 | 349.7 | 289.0 | 196.7 |
| 4.5 | 107 | 0.360 | 340 | 1709.0 | 1384.3 | 1093.8 | 778.7 | 615.2 | 517.0 | 427.3 | 290.8 |
| 5.0 | 146 | 0.370 | 470 | 2362.5 | 1913.6 | 1512.0 | 1076.4 | 850.5 | 714.6 | 590.6 | 402.0 |
| 5.5 | 195 | 0.360 | 610 | 3066.2 | 2483.6 | 1962.4 | 1397.0 | 1103.8 | 927.5 | 766.5 | 521.7 |
| 6.0 | 253 | 0.350 | 770 | 3870.4 | 3135.1 | 2477.1 | 1763.5 | 1393.4 | 1170.8 | 967.6 | 658.6 |
| 6.1 | 266 | 0.346 | 800 | 4021.2 | 3257.2 | 2573.6 | 1832.2 | 1447.6 | 1216.4 | 1005.3 | 684.2 |
| 6.2 | 279 | 0.343 | 840 | 4222.3 | 3420.1 | 2702.3 | 1923.8 | 1520.0 | 1277.2 | 1055.6 | 718.5 |
| 6.3 | 293 | 0.340 | 870 | 4373.1 | 3542.2 | 2798.8 | 1992.5 | 1574.3 | 1322.9 | 1093.3 | 744.1 |
| 6.4 | 307 | 0.335 | 900 | 4523.9 | 3664.4 | 2895.3 | 2061.2 | 1628.6 | 1368.5 | 1131.0 | 769.8 |
| 6.5 | 321 | 0.330 | 930 | 4674.7 | 3786.5 | 2991.8 | 2129.9 | 1682.9 | 1414.1 | 1168.7 | 795.4 |
| 6.6 | 336 | 0.326 | 960 | 4825.5 | 3908.6 | 3088.3 | 2198.6 | 1737.2 | 1459.7 | 1206.4 | 821.1 |
| 6.7 | 352 | 0.323 | 1,000 | 5026.5 | 4071.5 | 3217.0 | 2290.2 | 1809.6 | 1520.5 | 1256.6 | 855.3 |
| 6.8 | 368 | 0.320 | 1,030 | 5177.3 | 4193.6 | 3313.5 | 2358.9 | 1863.8 | 1566.1 | 1294.3 | 881.0 |
| 6.9 | 384 | 0.315 | 1,060 | 5328.1 | 4315.8 | 3410.0 | 2427.6 | 1918.1 | 1611.8 | 1332.0 | 906.6 |
| 7.0 | 401 | 0.310 | 1,090 | 5478.9 | 4437.9 | 3506.5 | 2496.3 | 1972.4 | 1657.4 | 1369.7 | 932.3 |
| 7.1 | 419 | 0.305 | 1,120 | 5629.7 | 4560.1 | 3603.0 | 2565.0 | 2026.7 | 1703.0 | 1407.4 | 957.9 |
| 8.5 | 718 | 0.235 | 1,480 | 7439.3 | 6025.8 | 4761.1 | 3389.5 | 2678.1 | 2250.4 | 1859.8 | 1265.8 |
| 9 | 853 | 0.210 | 1,570 | 7891.7 | 6392.3 | 5050.7 | 3595.6 | 2841.0 | 2387.2 | 1972.9 | 1342.8 |

Source: Gipe, Wind Works - www.wind-works.org/images/AverageWindSpeedtoSpecificYieldwithDetailfrom900to1100.xls

Assumed efficiency based on published data, hub height wind speed and Raleigh Distribution, k=2.

For information on the methods and assumptions used see:

Wind Power: Renewable Energy for Home, Farm, and Business (2004)

Warning: Actual performance may vary.

Wind farm output for specific average velocity

| Number of Turbines | Output (MWh/yr) for different Turbine Sizes (kW) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2500 | 2000 | 1500 | 1000 | 750 | 600 | 500 | 300 |
| 30 | 131192.9 | 106266.3 | 83963.5 | 59774.8 | 47229.4 | 39685.9 | 32798.2 | 22323.3 |
| 29 | 126819.8 | 102724.0 | 81164.7 | 57782.3 | 45655.1 | 38363.0 | 31705.0 | 21579.2 |
| 28 | 122446.7 | 99181.8 | 78365.9 | 55789.8 | 44080.8 | 37040.1 | 30611.7 | 20835.1 |
| 27 | 118073.6 | 95639.6 | 75567.1 | 53797.3 | 42506.5 | 35717.3 | 29518.4 | 20091.0 |
| 26 | 113700.5 | 92097.4 | 72768.3 | 51804.8 | 40932.2 | 34394.4 | 28425.1 | 19346.9 |
| 25 | 109327.4 | 88555.2 | 69969.6 | 49812.3 | 39357.9 | 33071.5 | 27331.9 | 18602.7 |
| 24 | 104954.3 | 85013.0 | 67170.8 | 47819.8 | 37783.6 | 31748.7 | 26238.6 | 17858.6 |
| 23 | 100581.2 | 81470.8 | 64372.0 | 45827.3 | 36209.2 | 30425.8 | 25145.3 | 17114.5 |
| 22 | 96208.1 | 77928.6 | 61573.2 | 43834.8 | 34634.9 | 29103.0 | 24052.0 | 16370.4 |
| 21 | 91835.0 | 74386.4 | 58774.4 | 41842.3 | 33060.6 | 27780.1 | 22958.8 | 15626.3 |
| 20 | 87461.9 | 70844.2 | 55975.6 | 39849.8 | 31486.3 | 26457.2 | 21865.5 | 14882.2 |
| 19 | 83088.8 | 67302.0 | 53176.9 | 37857.4 | 29912.0 | 25134.4 | 20772.2 | 14138.1 |
| 18 | 78715.7 | 63759.8 | 50378.1 | 35864.9 | 28337.7 | 23811.5 | 19678.9 | 13394.0 |
| 17 | 74342.6 | 60217.5 | 47579.3 | 33872.4 | 26763.4 | 22488.7 | 18585.7 | 12649.9 |
| 16 | 69969.6 | 56675.3 | 44780.5 | 31879.9 | 25189.0 | 21165.8 | 17492.4 | 11905.8 |
| 15 | 65596.5 | 53133.1 | 41981.7 | 29887.4 | 23614.7 | 19842.9 | 16399.1 | 11161.6 |
| 14 | 61223.4 | 49590.9 | 39182.9 | 27894.9 | 22040.4 | 18520.1 | 15305.8 | 10417.5 |
| 13 | 56850.3 | 46048.7 | 36384.2 | 25902.4 | 20466.1 | 17197.2 | 14212.6 | 9673.4 |
| 12 | 52477.2 | 42506.5 | 33585.4 | 23909.9 | 18891.8 | 15874.3 | 13119.3 | 8929.3 |
| 11 | 48104.1 | 38964.3 | 30786.6 | 21917.4 | 17317.5 | 14551.5 | 12026.0 | 8185.2 |
| 10 | 43731.0 | 35422.1 | 27987.8 | 19924.9 | 15743.1 | 13228.6 | 10932.7 | 7441.1 |
| 9 | 39357.9 | 31879.9 | 25189.0 | 17932.4 | 14168.8 | 11905.8 | 9839.5 | 6697.0 |
| 8 | 34984.8 | 28337.7 | 22390.3 | 15939.9 | 12594.5 | 10582.9 | 8746.2 | 5952.9 |
| 7 | 30611.7 | 24795.5 | 19591.5 | 13947.4 | 11020.2 | 9260.0 | 7652.9 | 5208.8 |
| 6 | 26238.6 | 21253.3 | 16792.7 | 11955.0 | 9445.9 | 7937.2 | 6559.6 | 4464.7 |
| 5 | 21865.5 | 17711.0 | 13993.9 | 9962.5 | 7871.6 | 6614.3 | 5466.4 | 3720.5 |
| 4 | 17492.4 | 14168.8 | 11195.1 | 7970.0 | 6297.3 | 5291.4 | 4373.1 | 2976.4 |
| 3 | 13119.3 | 10626.6 | 8396.3 | 5977.5 | 4722.9 | 3968.6 | 3279.8 | 2232.3 |
| 2 | 8746.2 | 7084.4 | 5597.6 | 3985.0 | 3148.6 | 2645.7 | 2186.5 | 1488.2 |
| 1 | 4373.1 | 3542.2 | 2798.8 | 1992.5 | 1574.3 | 1322.9 | 1093.3 | 744.1 |

## A.8 TECHNOLOGY MODELLING CALCULATIONS

This screenshot only gives the detail of one of the technologies modelled – wind, however, all technologies have a section in this sheet.

### Technical Calculations and Data

This tab includes most of the information used to calculate the outputs found in the Outputs page. Specifically, there is a table of data for each technology including costings, minimum size, emissions factors and lifetime of the technology; sources are referenced in a comment. There are also sections for each technology below the table, which detail the technical assumptions which combined with the input data provide the basis for the calculations for energy generation, size, number of units (where relevant), land area (where relevant) and number of RECs produced (where relevant) for each of the technology options. The RECs calculations take into account the multiplier for small scale (<1.5kW) systems. That is the first 1.5kWs of any renewable energy generation system is eligible for 5 times the number of RECs. Finally, the pink shaded table at the top of this tab houses the costing and emissions calculations for each of the technologies based on size and energy generation and the data in the blue table. For more information as to these technical calculations see the flow charts in the attached document.

| Technology | Minimum Unit Size [MW] | Maximum Unit Size [MW] | Lifetime [years] | Capital cost [$M/MW] | Fixed O&M costs | Variable Costs - Fuel and Increm'l [$/MWh] | Transmission Costs [$/kW] | Capacity factor [%] | Emissions factor [$tCO_2e$/MWh] | Size [MW] | Generation capacity [MWh/yr] | Capital Cost [$M] | Energy cost [$/MWh] | Emissions Abatement [tCO2e] | Area required [m2] | Number of Units | Feedstock required (tonnes) | % Energy Use accounted for |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wind** | 0.5 | 2.5 | 25 | 2.5 | 0 | 15 | 50 | 35% | 0 | 0.50 | 1093 | $1.25 | $127.31 | 973 | 78400 | 1 | --- | 374.41% |
| **Solar PV** | 0.001 | 30 | 25 | 7 | 0 | 13 | 50 | 20% | 0 | 0.23 | 292 | $1.63 | $489.28 | 260 | 3914.4 | 233 | --- | 100.12% |
| **Cogeneration** | 0.01 | 30 | 25 | 1.55 | 0 | 22.2 | [illegible] | [illegible] | 0.3 | 0.04 | 387 | $0.06 | $39.89 | 228 | --- | --- | --- | 132.60% |
| **Agricultural biomass** | 0.1 | 30 | 25 | 4 | 0 | 45.5 | [illegible] | [illegible] | 0 | 0.00 | 0 | $0.00 | $0.00 | 0 | 0 | --- | 10 | 0.00% |
| **Mini Wind** | 0.01 | 0.5 | 15 | 3.7 | 0.006 | 0 | [illegible] | [illegible] | 0 | 0.12 | 308 | $0.44 | $170.25 | 274 | --- | 12 | --- | 105.48% |

**Source:** MMA, 2003, Stucley et al, 2004 and RIRDC, 2008

### Wind Calculations

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Include - based on wind speed | 1 | | | | | | |
| Include - based on land availability | 1 | | | | | | |
| Include | 1 | | | | | | |
| | | | | | | | |
| Turbine Size (kW) | 2500 | 2000 | 1500 | 1000 | 750 | 600 | 500 |
| Diameter | 80 | 72 | 64 | 54 | 48 | 44 | 40 |
| | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Energy Produced (MWh/yr) | 4373.097 | 3542.209 | 2798.78 | 1992.4923 | 1574.3149 | 1322.861835 | 1093.274243 |
| Number of Turbines | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Size of farm (KW) | 2500 | 2000 | 1500 | 1000 | 750 | 600 | 500 |
| | | | | | | | |
| Energy Produced (MWh/yr) | 1093.3 | | | | | | |
| Turbine size (kW) | 500 | | | | | | |
| Diameter | 40 | | | | | | |
| Number of Turbines | 1 | | | | | | |
| Size of farm (KW) | 500 | | | | | | |
| Footprint (m2) | 1416 | | | | | | |
| Area of cleared land required (m2) | 78400 | | | | | | |
| | | | | | | | |
| Wind generation (MWh/y) | 1093.274 | | | | | | |
| Wind size (MW) | 0.5 | | | | | | |
| Wind area (m2) | 78400 | | | | | | |

## A.8 TECHNOLOGY SUMMARIES

Each technology option in CEDAT has a summary sheet, a screenshot is given of the Solar PV sheet as an indication.

### Your Community Solar PV Project: Analysis of CEDAT results and more information

**Based on your input data solar PV is a Poor technology option for your community energy project.**

**Technical considerations:**

The optimum technical arrangement for your community wind project, based on CEDAT's analysis is **233** 1kW solar PV systems, with a footprint of **3914** m2, producing approximately **292.34** MWh of electricity per year or **100.1%** of your community's energy needs.

Please note that the information above are estimates based on annual average solar insolation in your area and that generation capacity and optimum size of solar systems are additionally influenced by the inclination (tilt) and orientation (direction) of the surface (e.g. a roof) on which they are mounted. Other factors which affect technical performance include: fouling (getting dirty); the brand of cell and its efficiency as different PV manufacturers produce cells of different efficiency; and age as the efficiency of solar panels declines slightly with age.

**Environmental considerations:**

A community solar PV project of this size will result in an approximate carbon abatement of **260** tonnes of CO2 per annum. That is the equivalent of taking 61 cars off the road permanently.

**Siting considerations:**

In addition to requiring the amount of land detailed above, and preferably a site with little cloud cover and high solar insolation, there is one other main factor to consider when siting a solar system - shading. Your chosen site will produced maximum power, if the site is not shaded at any point during the day. Shading will decrease the energy output of your system.

**Economic considerations:**

Based on CEDAT's analysis, your community solar project will likely cost **$1,631,000** in upfront capital, and over the project life will cost approximately **$489.28** per MWh of electricity generated (excluding the income generated by RECs) or **$1,012** per household per year (including the income from RECs) in 2009 dollars. Compare this with a current approximate energy cost for households in your community of **$526** per household per year.
This represents an increase **$487** per year. This costing takes into account the income from Renewable Energy Certificates and the extra subsidy available to small scale renewable energy projects as part of the increased Renewable Energy Target. This analysis assumes that the solar systems will be spread out over most or all of the households in your community. This is because the subsidy is only available for the first 1.5kW of each system, thus the more the systems are disaggregated across different households, the greater the subsidy available.
The per household analysis is an indicator and will only eventuate if all households in your community participate in the financing of the project. See the social and institutional considerations section for financing mechanisms.

Please note, community energy projects can be expensive, they require a lot of up-front capital. However, transforming Australia's energy sector to be much less greenhouse intensive is an important task, one that community energy projects like yours are contributing to.

**More information on solar PV energy:**

Solar Energy Industries Australia (2009) *PV Grid connected systems (non-UPS): System design guidelines*

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Sydney Energy Co-op (2009) *Photovoltaics - Energy from the sun*, < energycoop.com.au/content/en/solar>
Kreith F. and Goswami D.Y., (2007) *Handbook of energy efficiency and renewable energy* .

**More information about community energy projects:**

Canadian Renewable Energy Alliance (2006) *Community Power – the Way Forward*
Community Energy Scotland (2009) *Community Renewable Energy Toolkit*
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Greenpeace (2005) *Decentralising Power: An energy revolution for the 21st Century*
Thompson, B (2008) *Decentralised Energy – in the Victorian Context* Moreland Energy Foundation
URBED, (2003) *Energy: the future generation. Co-operative opportunities.* The Union of Cooperative Enterprises, UK.
Walker, G. (2008) 'What are the barriers and incentives for community-owned means of energy production and use?' *Energy Policy*, Issue 36 December 2008

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