Estimating Tradeable Certificates Created by Small-Scale Renewable Energy Systems

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Abstract Recent industry development programs in several countries have involved the use of tradeable certificate schemes as means for electricity generators and retailers to fulfil mandatory requirements for renewable energy generation. Renewable energy generation will potentially also yield carbon offsets under domestic emissions constraints involving emissions trading schemes. This paper develops a novel framework for estimating the amount of renewable energy certificates and carbon emissions offsets that may be created by a wide range of small scale renewable energy systems. A methodology is developed that requires information on only two parameters of the generating system, namely the specific fuel consumptions of the renewable energy system and an appropriate baseline system.

Keywords: Renewable energy; Market mechanisms; Emissions trading.

1 INTRODUCTION

Concerns over fossil fuel resource depletion, energy security and the concentration of greenhouse gas emissions in the atmosphere have highlighted the importance of sustainable sources of energy. Given the substantial and strategic role of electricity generation in fossil fuel resource consumption and atmospheric carbon emissions, the electricity sector is a focal point in these issues. For these reasons, national governments have recognized the importance of renewable sources of energy in their energy mix. Amongst developed countries there has been an increased impetus for research in renewable energy technologies and development of a competitive renewable energy industry.

Typically, established energy policy and electricity grid operations discriminate against renewable energy technologies, and constitute a major barrier to their widespread adoption. Important barriers include subsidies for fossil fuels, particularly for remote applications. Power balancing requirements and nodal pricing policies frequently prevent renewable penetration on large electricity grids. Furthermore, externalities resulting from fossil fuel electricity generation are generally not internalised within the price of electricity. The externality of major international concern is that of greenhouse gas emissions, primarily carbon dioxide. In some instances, governments have already taken action to incorporate externalities of electricity generation, most notably the regulation of sulphur dioxide in the north east of the United States using a cap-and-trade system.

Recent policy measures in several countries aim to encourage renewable energy generation using tradeable certificates (see Amundsen and Mortensen 2001, Lawaetz 2001, Watt and Outhred 2001). In Australia these instruments are referred to as Renewable Energy Certificates, in the United Kingdom as Renewable Obligation Certificates, and in Denmark as Green Certificates. Similarly, proposed measures to constrain carbon emissions also involve tradeable carbon emissions permits or credits. This paper develops a novel framework for estimating the amount of renewable energy certificates and carbon emissions credits that may be created by a wide range of small scale renewable energy systems. A methodology is developed that requires information on only two parameters, namely the specific fuel consumptions of the renewable energy system and of an appropriate baseline generation system.

2 MARKET MECHANISMS AND RENEWABLES

National governments have long maintained programs for research and development in renewable energy technologies, and have implemented measures aimed at the development of their renewable energy industry, both as manufacture of equipment and generation of electricity. National energy policies have recently paid more attention to the role of renewables in the future of domestic energy sectors. Government programs have begun to focus on assisting renewables to overcome a number of barriers to their up-take.

Several countries have imposed legislated mandatory targets for renewable energy generation in electricity supply. Targets are manifest as a requirement imposed on generators or retailers of electricity to satisfy a certain minimum percentage or absolute amount in gigawatt hours of their electricity from renewable sources. Generally, mandatory targets operate via tradeable certificate schemes. Eligible renewable energy based generation of electricity gives rise to an instrument that may then be traded on a market and ultimately used by liable parties under the legislation to acquit their obligation.

One such scheme is the Mandatory Renewable Energy Target (MRET) in Australia. The scheme commenced in April 2001, and requires an additional 9,500 gigawatt hours of renewable energy electricity generation by 2010, to be maintained through to 2020. Under this scheme, generation of electricity, or the displacement of fossil fuel electricity generation, from eligible sources of renewable energy allows the creation of a Renewable Energy Certificate (REC). The liable parties under the scheme, retailers or notional retailers of electricity, must submit an appropriate number of RECs to satisfy their obligations for having sufficient renewable energy generation within their portfolio of electricity supply. Each REC represents 1 megawatt hour of renewable energy electricity generation. Should a retailer default on their obligation, they are subject to a charge of AUD 40 per megawatt hour for their shortfall in RECs.

Small-scale renewable energy systems, both grid connected and remote area power supply (RAPS) systems, that rely on solar photovoltaic, wind turbine, and small hydro technologies for their renewable energy input are eligible for creating RECs.

3 GREENHOUSE GAS EMISSIONS CONSTRAINTS AND RENEWABLES

International concerns over anthropogenic climate change caused by the emission of greenhouse gases have mounted substantially over recent years. The United Nations Framework Convention on Climate Change (UNFCCC) and the subsequent Kyoto Protocol aim to stabilise greenhouse gas concentrations at levels that would prevent dangerous anthropogenic interference with the global climate. Industrialised countries accepted different targets of emission reduction in order to achieve the overall emissions reduction target. National emissions quotas require countries to develop domestic emissions regulation, which, to a large extent, will consist of tradeable emissions permit schemes. Although some still believe the Protocol will not be ratified in its present form, the general consensus, given mounting scientific evidence of climate change, is that binding limits on emissions are inevitable, and market based mechanisms are the most efficient means of achieving these limits.

The Protocol allows three flexibility mechanisms, international emissions trading, Joint Implementation (JI) and the Clean Development Mechanism (CDM), with the aim of allowing industrialised countries to achieve their emission limit at least cost to their economy (UNFCCC 1998). Several industrialised countries have developed proposals for domestic emissions trading schemes, generally of an allowance-based type, and schemes are being, or have been, established by a number of governments including those of the United Kingdom and Denmark (Ekins and Barker 2001).

Where renewable sources of energy displace energy generated from fossil fuels, the renewable energy system is offsetting carbon emissions, and thus is likely to be eligible to create a carbon emissions credit or offset. This is certainly the case under the Kyoto Protocol mechanisms for Clean Development Mechanism (CDM) and Joint Implementation (JI) projects. Domestic carbon emissions regulation is likely to reflect this. Carbon emissions permits or emissions reduction units, would be denominated in tonnes of carbon dioxide equivalent, a unit that provides a common measure for the six greenhouse gases covered by the Kyoto Protocol.

4 CONTEXT FOR THE MODEL

The framework presented in this paper is intended to create a model useful in the pre-feasibility analysis of projects involving small scale renewable energy systems. The model intends to provide a framework for estimating the amount of renewable energy certificates and carbon emission reductions that can be produced by a renewable energy system. The framework specifically relates to the Australian MRET scheme, and the generic emissions reduction framework for small-scale CDM projects under the Kyoto Protocol that were encapsulated within the Marrakech Accords that resulted from COP7 (UNFCCC 2001).

The model will assist in the assessment of the commercial benefits of renewable energy technologies by relating energy generation systems to emerging markets. Renewable energy system simulation programs including RAPSIM, HOMER and HYBRID2 will be used to calibrate the theoretical model to simulated data.

Ultimately the project intends to culminate in an interactive internet-based model that estimates quantities of renewable energy certificates and carbon emission reductions for a wide range of renewable energy and hybrid renewable energy systems, whether they be connected to the electricity grid or remote area power systems.

5 THE MODEL

Consider an application or a load that is to be met by a renewable energy (RE) or a renewable energy hybrid system. To determine the emissions credits or RECs created by the RE system we need to compare the impact of that system with that of an appropriate baseline system. The model is developed for the case of a RAPS system as the most general case, which can be summarised in the following two diagrams.

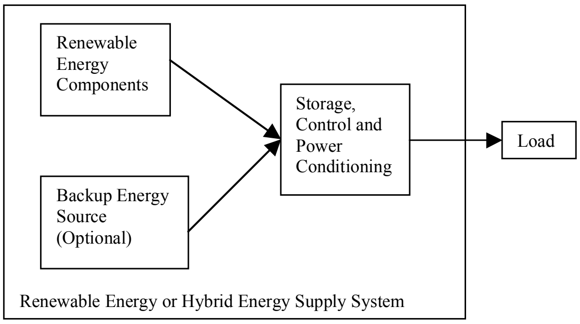

Diagram 1: Hybrid renewable energy system

In Diagram 1, a hybrid RE energy system is represented schematically showing the renewable energy technology components which create electricity from renewable sources of energy such as solar radiation, wind, and hydro. A backup source of energy is included, which is typically a diesel generator in RAPS system. Storage, control, and power conditioning are also represented, prior to the electricity being supplied to the load on the system.

The baseline for a RAPS system will involve the load being met by a conventional fossil fuel-based source of energy. Typically for a RAPS system this will be a diesel generator, however the framework developed in this paper has the flexibility to incorporate alternatives such as gas. Diagram 2 shows the conventional baseline system that is appropriate for a RAPS system.

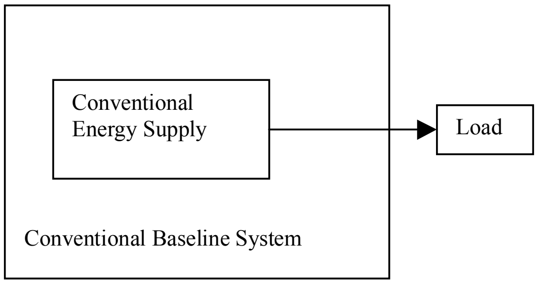

Diagram 2: Conventional baseline for a RAPS system

The number of RECs created by the RE system will be determined by the difference in conventional energy consumption between the RE and baseline systems. For example, presume the electrical load over a certain period is 10 MWh. If the hybrid renewable energy supply system used 4 MWh of conventional energy to meet this load, with the remaining 6 MWh being supplied by the renewable energy components, the RE system has displaced 6 MWh of conventional energy. Given that 1 REC represents 1 MWh of electrical energy from a renewable energy source, the RE system would create 6 RECs.

Furthermore, the carbon emissions reductions can be calculated using a similar method. Presume the production of electricity using the conventional energy source resulted in the emission of Z tonnes of carbon-equivalent (CO2-e) per kWh of electricity supplied to meet the load imposed by the consumer of electricity. The hybrid renewable energy system creates 6 x 1000 x Z carbon emission reduction units. The overall carbon emissions reduction of the hybrid renewable energy systems depends on the carbon intensity of the baseline conventional energy generation system, that is, the carbon intensity of the fossil fuel source and the efficiency of the generating technology.

Using such a procedure, the task is one of estimating the conventional energy required to meet the load under an appropriate baseline, and also the conventional energy required by the hybrid RE system in order to meet the load. Essentially, the model must estimate the fraction of conventional energy that is displaced by the hybrid RE system. In the next section, small-scale RAPS systems are considered in detail.

Although the focus of this paper is on small-scale RAPS systems, the model can equally be applied to small-scale grid-connected renewable energy systems. On-grid systems represent a special case of the model whereby the full output of the renewable energy system is used to offset the baseline system. Fully incorporating this special case represents a further area of model development.

5.1 Small Scale RAPS Systems

In the case of small scale RAPS systems, the baseline is generally a stand-alone diesel generator. Therefore, the benefits in terms of carbon credits or RECs created will be a function of incremental savings in diesel fuel due to the energy supplied by the RE system. The baseline system for a typical hybrid RE RAPS system is shown schematically in Diagram 3 below.

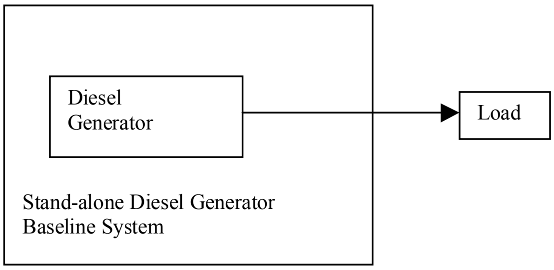

Diagram 3: Baseline system for a RAPS System

In the baseline system the diesel generator meets the entire load directly. The mean daily load on the system is defined as L_{av} kilowatt hours (kWh) per day. The mean daily fuel consumption for the baseline systems is FC_b litres per day. A variable known as the specific fuel consumption can be used to provide a measure of the effectiveness or efficiency of the system. The specific fuel consumption indicates the amount of the average daily load that can be provided by the system from each litre of diesel fuel consumed. Therefore, the specific fuel consumption for the baseline system, SFC_b, can be expressed as:

$$SFC_b = L_{av} / FC_b \,. \qquad (1)$$

By a similar line of reasoning, the specific fuel consumption of the RE system, SFC_s, can be expressed as:

$$SFC_s = L_{av} / FC_s \,, \qquad (2)$$

where FC_s is the mean daily fuel consumption for the RE system, and the mean daily load, L_{av}, is the same as for the baseline system.

In the special case of a stand-alone RE system, with no fossil fuel backup energy source, the value of SFC_s, is infinite. That is, the mean daily load is met with zero fuel consumption.

5.2 Renewable Energy Certificates

The number of RECs that could be created by installing and operating a hybrid RE system, that is one incorporating the RE components as schematically indicated in Diagram 1, can be defined as that portion of the load that can be attributed to the RE components of the system (in MWh). Assuming that the fuel consumption of the hybrid RE system is less than that of the baseline system, the impact of the hybrid RE system can be measured in terms of this reduction of fuel consumption. In the terminology introduced above, the fuel consumption in the RE system is FC_s. If this amount of fuel was consumed in the baseline system, the amount of energy produced would be FC_s x SFC_b, where SFC_b represents the energy in kWhs delivered to the load for each litre of fuel consumed by the baseline system.

Therefore, the portion of the load, in kWh, that can be attributed to the RE system can be expressed as:

$$RE = L_{av} - FC_s \times SFC_b \,. \qquad (3)$$

Given that under MRET a REC is defined as representing 1 MWh (or 1000 kWh) of renewable energy generation, the number of RECs, REC_s, produced by the RE components of the system is:

$$REC_s = \left(L_{av} - FC_s \times SFC_b\right) / 1000 \,. \qquad (4)$$

However, for the purposes of this model we will assume that the RECs are in units of kWh. Given that the model is to address small-scale hybrid RE systems, the number of RECs created will be small for many individual systems if the units are retained as MWh. Therefore equation (4) reverts to:

$$REC_s = \left(L_{av} - FC_s \times SFC_b\right). \qquad (4a)$$

From equation (2) above, the fuel consumption of the hybrid RE system can be expressed as:

$$FC_s = L_{av} / SFC_s \,. \qquad (5)$$

Substituting equation (5) into equation (4a) gives:

$$REC_s = L_{av}\left(1 - \left[SFC_b / SFC_s\right]\right). \qquad (6)$$

Equations (4) and (6) display intuitively correct behaviour for a stand-alone RE system. Where there is no fossil fuel generation component in a system, the fuel consumption in the stand-alone RE system, FC_s, is zero and consequently the SFC_s value becomes infinitely large. In equation (4) the REC_s value simply reduces to the mean daily load, L_{av}, divided by 1000 to give a number of RECs or output or RE generation in MWh. That is, the entire load is being met by RE generation, and the number of RECs reflects this as it is equal to the mean daily load. Similarly, in equation (6) the ratio of specific fuel consumptions approaches zero as SFC_s becomes infinite and the same result is obtained.

5.3 Carbon Emission Reductions

The carbon emission reductions, CER_s, created by a renewable energy project should be based on the amount of fossil fuel displaced by the use of renewable sources of energy, that is, on the difference in fuel consumption between the hybrid RE system and the baseline system. Equation (7) shows this relationship:

$$CER_s = (FC_b - FC_s) \times C_f, \qquad (7)$$

where C_f is the carbon content of the fossil fuel used in the baseline and hybrid energy systems, that is the amount of carbon in kilograms emitted as greenhouse gases for each litre of fuel consumed. For RAPS systems the appropriate fuel to consider is diesel, and in this model we assume that the baseline fuel and fuel used in the hybrid system are the same. This is not unreasonable because the choice of the baseline system would generally reflect the readily available fuel which, presumably, would be used for the backup in the RE system.

If this equation is expressed in terms of the specific fuel consumption values defined earlier we get:

$$CER_s = \left(\frac{L_{av}}{SFC_b} - \frac{L_{av}}{SFC_s} \right) \times C_f. \qquad (8)$$

Or alternatively,

$$CER_s = L_{av} \times \left(\frac{1}{SFC_b} - \frac{1}{SFC_s} \right) \times C_f. \qquad (9)$$

If the hybrid RE system is to create carbon emission reductions then its fuel consumption must be lower than that of the baseline system. Consequently, the baseline system's specific fuel consumption must be smaller than that of the hybrid RE system. Equation (9) produces a positive result as expected.

6 CALCULATION METHODOLOGIES

In the model presented in section 5, both the number of RECs created and the amount of carbon emissions reduction due to a hybrid RE system are functions of mean daily load, L_{av}, the specific fuel consumption of the system in question, SFC_s, and the specific fuel consumption of the baseline system, SFC_b. An additional term in the carbon emissions reduction equation, C_f, relates fuel savings to carbon emissions reductions for a particular fossil fuel.

Equations (6) and (9) also indicate that both the number of renewable energy certificates and the amount of carbon emissions reduction are directly proportional to the load being met by the system. This raises the possibility of defining REC_s and CER_s in terms of each unit of load being met.

That is, the number of RECs can be defined in terms of the number of RECs created per kWh of load met. Likewise, the amount of carbon emission reduction can be presented as the CER_s per kWh of load met. Equation (6) becomes:

$$REC_s / L_{av} = (1 - SFC_b / SFC_s), \qquad (10)$$

where units of kWh are used rather than MWh for the reasons discussed in section 5.

Equation (9) can be expressed in the same form:

$$CER_f / L_{av} = \left(\frac{1}{SFC_b} - \frac{1}{SFCs} \right) \times C_f. \qquad (11)$$

Equations (10) and (11) indicate that both the number of RECs per unit of load met, and the number of carbon emissions reductions per unit of load met, can be determined using just two variables: the specific fuel consumption for the baseline case and the specific fuel consumption for the hybrid RE system.

Using the results in equations (10) and (11), lines of constant REC_s or CER_s value can be drawn on a plot of System Specific Fuel Consumption versus Baseline Specific Fuel Consumption. The lines of constant REC_s and CER_s value are referred to as iso-REC and iso-CER curves, respectively. Iso-REC curves are straight lines as illustrated in Figure 1.

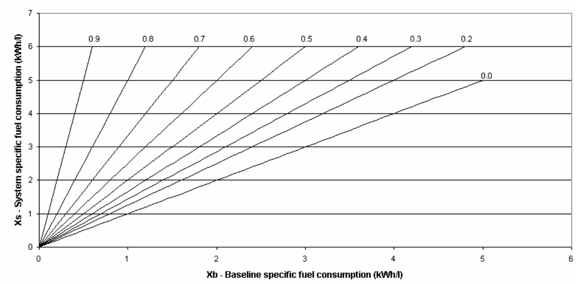

Figure 1: Iso-RECs curves

Figure 1 shows that where $SFC_b = SFC_s$, the number of RECs is zero, as is to be expected from the definition of each specific fuel consumption variable. If this condition applies, then the same amount of fuel is used in both systems and there is no net advantage in renewable energy generation due to using the hybrid RE system. If SFC_s were to be less than SFC_b, more fuel is being consumed in the hybrid RE system compared with the baseline, thus no RECs are produced. For a given value of

SFC_b, the number of RECs increases as SFC_s increases (that is, as the fuel consumption of the hybrid RE system decreases). In the special case of a stand-alone RE system, the value of REC/L_{av} is 1, that is, the entire load is served by renewable energy generation, and thus the number of RECs Created is equivalent to the load.

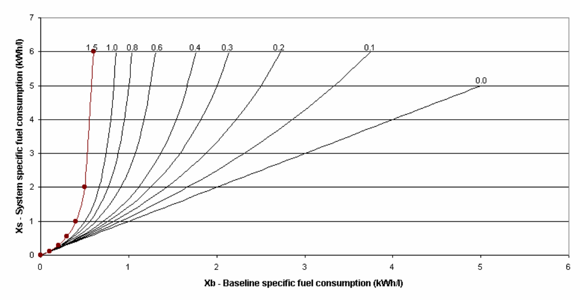

Figure 2: Iso-CER curves

Figure 2 shows iso-CER curves in the same System Specific Fuel Consumption versus Baseline Specific Fuel Consumption space. The interpretation of the plot for carbon emission reductions is slightly more complex. The iso-CER curves are denominated in units of litres of fuel per kWh of load met. These must be multiplied by the carbon content of the fuel used, C_f, to produce carbon emission reduction values. This can be seen from equation (11), where, in order to have only the specific fuel consumption variables on the right hand side of the equation, CER_f must be divided by C_f. This is shown in the following equation:

$$\frac{CER_s/C_f}{L_{av}} = \left(\frac{1}{SFC_b} - \frac{1}{SFC_s}\right). \qquad (12)$$

The variable CER_f/C_f is simply the number of units of fuel used, that is, the number of litres of diesel fuel if the baseline is a diesel-only system. The iso-CER lines are non-linear, as indicated in Figure 2. Once the values of SFC_b and SFC_s are known, the resulting CER_s/C_f can be read from the graph. The number of the carbon emission reduction credits is determined by multiplying this number by the carbon content of the fuel used, and the mean daily load on the system.

7 ADVANTAGES OF THE MODEL AND CONCLUSIONS

To determine the number of RECs and carbon emission reductions due to a hybrid RE system with this model, the user need only to determine two variables: the specific fuel consumption for the baseline system and the specific fuel consumption for the hybrid RE system. The first of these is relatively straightforward, and will depend on the size of the diesel generator and the nature of the daily load profile. Assuming best practice is used in sizing the diesel for the expected load, the baseline specific fuel consumption is merely a function of the load profile. The specific fuel consumption for the hybrid RE system is more difficult to determine as it will be a function of many factors including the size of the RE components, the size of the storage, and the relationship between the RE sources and the load profile. Simulations are required to produce specific fuel consumption data for various hybrid RE system types and associated load profiles using software such as RAPSIM, HOMER or Hybrid2. It may be possible to develop a series of generic relationships, graphically depicted as curves, reflecting the performance of well designed RE systems in a range of climate or resource conditions. This is an area for further research.

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