Scoping technology scenarios for a 100% Renewable Energy Rotorua

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Abstract

There is a move towards the use of renewable energy internationally in particular in Europe. In the countries which have been successful, like Denmark and Germany, the increasing use of renewable energy has been through a multi-resource approach. In Denmark the development has happened with an increase in energy efficiency, more use of bioenergy, more use of wind power, more use of solar energy and more use of waste heat from cogeneration of electricity and heat.

Rotorua has the potential to be New Zealand's first 100% renewable energy city. Rotorua has around 50,000 inhabitants and of total energy consumption, bioenergy is already estimated to cover around 25%, and by covering the low grade heat demand only, it is possible that bioenergy could supply 65% of Rotorua's total energy demand. On top of that there is geothermal and solar energy. In the paper a framework for Rotorua to become a 100% renewable energy city is developed using a technology scenario approach. A Business As Usual, a Green and a Super Green scenario have been developed. At this stage it only evaluates the residential sector. Although the target may be achieved in many different ways, the aim of the scenario development is eventually to identify the most cost-effective way for Rotorua to become a 100% renewable energy city – and evaluate environmental and socio-economic benefits.

Introduction

Worldwide there is a push towards the use of renewable energy. New Zealand already generates a significant part of its energy supply from hydro power, geothermal resources bioenergy and, increasingly, wind energy; all renewable energy sources. Of total energy consumption in NZ, renewable energy comprises 29% (Ministry for the Environment, 2001). Whilst most of the hydro resources suitable for electricity generation are being exploited, and recently the last large hydro project, Project Aqua, has been cancelled, there are still significant renewable energy resources in geothermal, bioenergy, solar energy and wind energy. Provided that these technologies are economically competitive, there is still significant potential to develop renewable energy sources in New Zealand.

This paper considers the way in which a New Zealand community, Rotorua, might move towards a goal of being New Zealand's first 100% renewable energy city by 2025 (100%

RER). Rotorua has around 50,000 inhabitants. Of total energy consumption, bioenergy is already estimated to cover around 25%. By covering the low grade heat demand only, it is possible that bioenergy could supply 65% of Rotorua's total energy demand (Nielsen, P.S. and Gifford, J., 2001) excluding transportation fuels. On top of or instead of some of the bioenergy resources, there are geothermal and solar energy resources. Energy efficiency and conservation also have a significant part to play. Wind energy is not a likely option as average wind speeds are low.

Several policies are currently being implemented which encourage decisions to switch to renewable energy in New Zealand. These include the Waste Minimisation Strategy (Ministry for the Environment, 2002a), the Climate Change Policy (The New Zealand Climate Change Project, 2002) and for the Renewable Energy Target (Ministry for the Environment, 2002b). Recently, a loan scheme for solar water heater installation has been implemented as part of the National Energy Efficiency and Conservation Strategy (Ministry for the Environment, 2001).

Of the many definitions of sustainable use, the one that is most often used is that from the report of the UN Commission on Sustainable Development, "The Brundtland Report" (Brundtland, 1987), which refers to *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. It leaves open the definition of "needs", both current and future. However for this exercise we assume that current standards of living will be maintained or improved with regard to health and social welfare needs. Furthermore the term renewable energy is used in this context as sustainable energy.

In Denmark the move towards renewable energy has happened with an increase in energy efficiency, more use of bioenergy, more use of wind power, more use of solar energy and more use of waste heat from cogeneration of electricity and heat (Nielsen, P.S., 2002). One project under development in Denmark is a 100% Renewable Island project, where Samsoe is endeavouring to achieve 100 % renewable heat and electricity supply by 2010 supported by funds from the Danish Energy Agency. Similarly, in Scotland, a strategy is being developed for the implementation of a 100% renewable energy system for the Island of Islay (Bronsdon 2001). A network of European "Brundtland Cities", (www.brundtlandnet.com) is also aiming for a high degree of renewable energy.

Methodology and approach

Three scenarios incorporating both technology improvements at both the end-use technology and the supply technologies have been developed. These are named "Business As Usual", "Green" and "Super Green". For each scenario we estimate the annual growth in demand over the period 2005 to 2030 and list the likely energy sources to be utilised over this period. Furthermore we consider how the available energy supply may be allocated to meet the demands in several aggregated demand categories, by means of allocation tables varying over time. We interpret the result of each scenario graphically in terms of the speed of approach to the 100% RER target. Of interest is whether the implied rates of change are achievable.

The model makes use of an “S” curve to describe the progress of changes in each energy source/end use category from the current situation to the end point. Such curves, in which change commences slowly, speeds up midway through the change period, and then slows down as the target is approached, have been used to describe the introduction (diffusion) of new technology to the market in both energy and other fields (Gilshannon 1996, Geroski 2000). Many different models of information theory lead to S curve functions, one of which is the logistic curve in the form:

$$y = \frac{e^x}{1 - e^x}$$

Parameters for this curve can be derived from considerations related to the way in which the new technology diffuses through a group of end users.

However, in the present case we are not predicting the progress of change, but rather endeavouring to determine the implications if certain changes occur at a certain rate. Thus we predetermine the curve shape by choosing curve parameters which quantify the time, t_p years, taken to reach a given percentage, p%, of the target, and the time taken, T years, to reach 50% of the target value.

The expression approaches the target value, say 100% conversion, exponentially, so a realistic end point of, say, $p = 99\%$ adoption has to be selected. In effect, t_p represents the project target time and T describes the pattern of progress towards the goal.

If T is small compared with t_p the change starts quickly and finishes slowly. If T is close to t_p, the change starts slowly and finishes quickly.

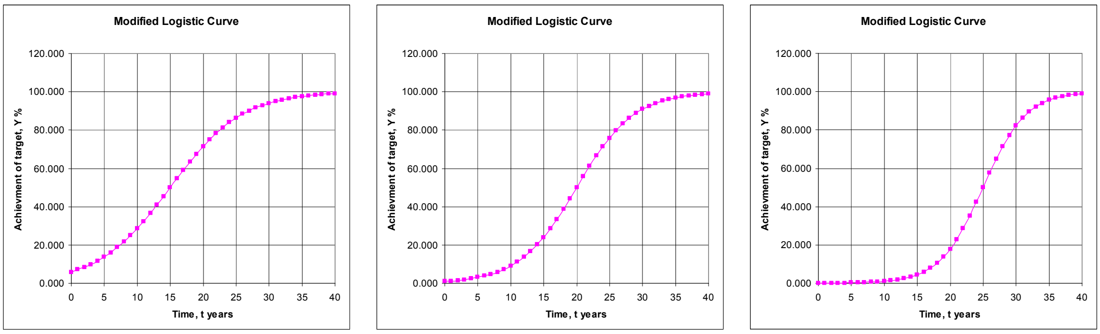
The expression we have derived to describe this pattern of change is:

$$y = \frac{e^z}{1 - e^z} \qquad \text{where} \qquad z = T \ln\left(\frac{p}{1-p}\right) \times \frac{\frac{t}{T} - 1}{t_p - T}$$

and y is the level of implementation.

For example the graphs in Figure 1 show implementation progress for levels of T of 15, 20 and 25 years over a period of 40 years for 99% implementation. Whilst values of the 3 curve parameters can be chosen for each combination of supply source and end use, for this exercise a p value of 99% is chosen for all combinations and all scenarios. Values of t_p are chosen separately for each of the three scenarios and values of T are chosen for each combination within a scenario depending on an estimate of the availability and likely speed of uptake of the technology.

Figure 1. Example of implementation curves for *p* = 99%, t_p = 40 years



***T* = 15 years** ***T* = 20 years** ***T* = 25 years**

Some of the factors which may affect the speed of uptake of the technology are economic advantages perceived by the end user, marketing efforts, information transfer generally and national and territorial government interventions such as loan subsidies, tax breaks, and pollution controls.

The model comprises allocation tables whereby sources of energy are allocated to particular aggregated end uses. Two allocation tables are given for each of the three scenarios (examples shown in Table 1 and Table 2). Table 1 is the estimated current position, whereas the second table is the targeted position at the end of the implementation period (both tables representing the Business As Usual scenario). The tables show, in the first column, the percentage of the total energy demand allocated to each aggregated end use, and in the body of the table, for each end use category, the percentage of energy of each type used to supply that particular demand (i.e. water heating).

For present use it is estimated that 45% of the energy for heating water comes from electricity produced by hydro power and 38% from electricity produced from fossil fuels. The split between hydro power and fossil fuels reflect the current electricity supply pattern in New Zealand. The percentage taken up by natural gas geothermal, wood and solar are figures taken from Rotorua data from Census 2001 keeping in mind that these data are to some extent uncertain. Although census data are uncertain they are still the most reliable data for estimating the split between the various energy sources. In Table 2 it has been estimated how the split could look in 2030 keeping in mind a 100% renewable energy sector. Therefore fossil electricity has been phased out being replaced by other renewable energy forms, in some cases with direct heating and in other cases with electricity generated from renewable energy sources other than hydro power.

Hydro power also takes up a higher proportion, for various reasons. 1) The hydro electricity takes up a larger share of the electricity consumption, not necessarily a larger amount of electricity. 2) Some of the electricity will be replaced by direct heating like heating water with solar energy, bioenergy or geothermal. 3) In the last two scenarios (the Green and Super Green scenarios) the total energy consumption will be declining during the period.

Table 1. Example of energy allocation table, present use, the Business As Usual scenario.

Current Allo. Pattern	Demand	Energy Source. Current end use %age						
End Use	%age	Hydro Elect	Fossil Elec	N. Gas	Geothermal	Wood	Solar	Totals
Water Heating	29.0	45	38	9	2	5	1	100
Space conditioning	22.0	25	20	15	20	20	0	100
Lighting	11.0	55	45	0	0	0	0	100
Refrigeration	10.0	55	45	0	0	0	0	100
Cooking	8.0	40	35	25	0	0	0	100
Miscellaneous electrical	20.0	55	45	0	0	0	0	100
	100							

Table 2: Example of energy allocation tables, future use year 2030 for the Super Green scenario.

Future Target Pattern	Demand	Energy Source. Future end use %age						
End Use	%age	Hydro Elect	Fossil Elec	N. Gas	Geothermal	Wood	Solar	Totals
Water Heating	30	40	0	0	25	10	25	100
Space conditioning	10	20	0	0	35	30	15	100
Lighting	20	100	0	0	0	0	0	100
Refrigeration	10	90	0	0	0	0	10	100
Cooking	10	90	0	0	0	10	0	100
Miscellaneous electrical	20	100	0	0	0	0	0	100
	100							

The target table (Table 2) expresses estimates of positions which may be reached at the end of the period chosen (year 2030) and takes into account such things as improvements in appliance efficiency, changes in fuel price relativity, and other factors that may have an impact on the pattern of energy use.

A further table of the same form gives values of T for each combination of end use and energy source. These values are chosen as estimates of how quickly changes may be implemented for each combination within the time period chosen.

The model then shows the pattern of transition along the defined S-curve in terms of percentages at rests of 5 years between the start and end points. These percentage tables are applied to a table of current estimated energy consumption to give the development of energy consumption patterns over time for each scenario. Over-arching these patterns are imposed multipliers based on percentage population growth estimates and percentage increase in energy consuming appliances per household.

An additional factor modeled for each entry in the allocation table is the improvement in the overall efficiency of the conversion technologies employed over time and the increase in end-use technologies. This improvement is also modeled using the logistic S-curve to describe the transition from current estimated efficiencies to future estimated efficiencies over the time period chosen for the scenario. These conversion efficiency change factors are also applied to the actual energy consumption estimates. A simplification in this preliminary study is that the technology penetration is focusing on the technologies of today. Later we will introduce S-curves for new end-use technologies for instance technologies, which are expected to be introduced to the market in 2015.

Results

The results of each scenario model are then expressed, for each rest, in tables of actual consumption patterns. An example of the tables is shown in Table 3 for the Green scenario, year 10. The figures show the energy consumption in MWh/year for the various end-uses taking into account its share of the total energy consumption and the particular assumptions behind that scenario and year. On the far right the energy consumption for the various renewable sources are totaled and the fossil fuels are totaled as well.

10	**Households**	**16285**						**Renewable v Fossil**	
End Use - Demand	**Hydro Elect**	**Fosl Elec**	**Gas**	**Geotherm**	**Wood**	**Solar**	**Totals**	**Renew**	**Fossil**
Water Heating	21555	15937	3984	5050	3346	4717	54588	34668	19921
Space conditioning	8060	4919	2958	8395	7284	2086	33702	25825	7877
Lighting	14655	9514	0	0	0	0	24169	14655	9514
Refrigeration	10802	7013	0	0	0	0	17816	10802	7013
Cooking	7377	4981	2435	0	642	0	15435	8019	7416
Miscellaneous electrical	21605	14026	0	0	0	0	35631	21605	14026
Totals	**84055**	**56390**	**9377**	**13445**	**11271**	**6803**	**181342**	**115574**	**65767**

Table 3. Table of energy consumption for the Green scenario transition periods 10 years after start of project (2015) in MWh/year for Rotorua.

Energy supply trends are shown in Figure 2 and the trend in the proportion of renewable and non-renewable energy, over time is illustrated in Figure 3. Both Figure 2 and Figure 3 illustrates the trend for the Green scenario.

Study of these output data can indicate what rates of implementation need to be achieved in order to meet the targets; how realistic the targets are for the assumed time periods, and whether the mix of changing technologies, conservation and reduction of energy use, is appropriate in the face of a growing population.

Figure 2. Energy supply trends from various energy sources for the Green scenario over 25 years from assumed start in 2005.

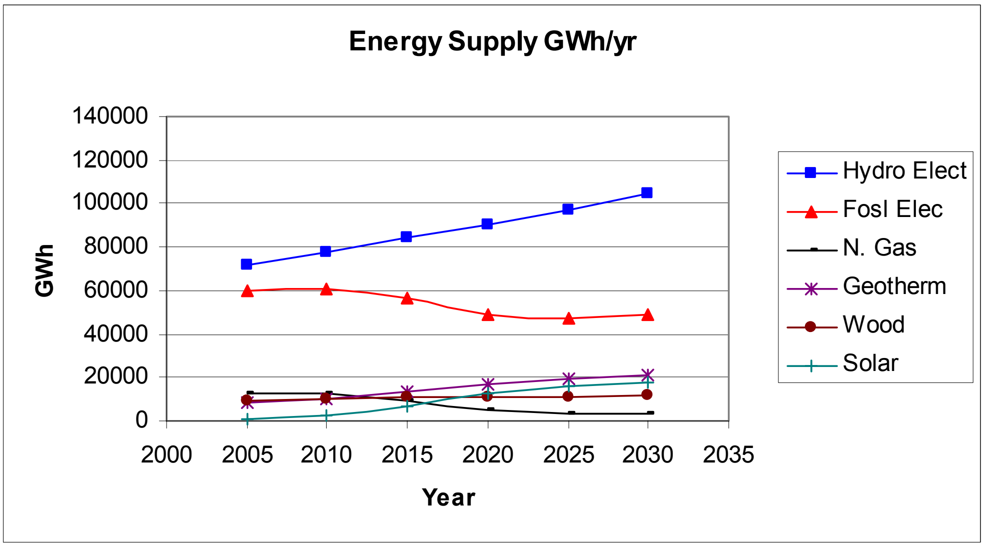
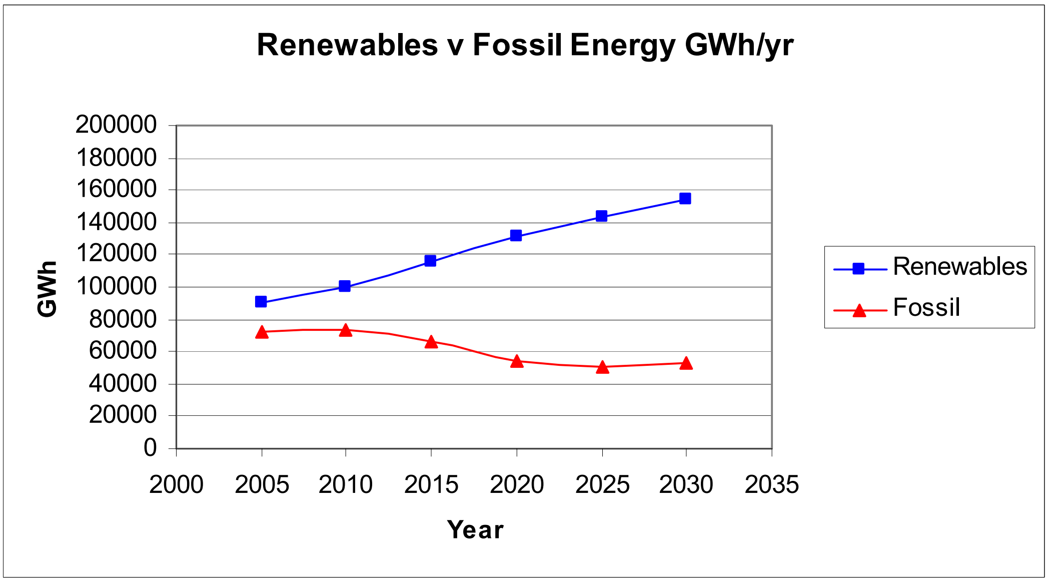


Figure 3: Total renewable energy supply versus fossil fuel supply in the Green scenario from year 2005 to 2030.



To use the model described above, allocation tables for current and future situations must be developed. Data for the current situation can be estimated from studies such as the HEEP project. Construction of a realistic future target allocation table depends on estimates of both energy demand and energy sources. Further enhancement of these estimates will be carried out in the next step of the project.

Figure 4 shows the percentage of renewable energy in the three scenarios (still only including domestic consumption). In the Business As Usual scenario there is no specific push toward renewable energy and no increase in energy efficiency is assumed. However scenario targets to maintain the present use of renewable energy (55%). The use of renewable energy still has to match an assumed increase of energy use by 1% per year.

In the Green scenario we assume a moderate increase of end-use efficiency by 20% over the period of 25 years or less than 1% increase per year over the period. This does influence the form of the curve in Figure 4. However, the largest influence comes from introducing more renewable energy. In particular electricity consumption used for space heating and for heating water is replaced with renewable energy sources like solar energy, bioenergy and geothermal energy. The Super Green scenario assumes that no electricity is used for space heating and for heating water. Electricity is only used for high grade end-uses (electric appliances). So it is the appropriate and efficient allocation of energy resources to end-use. In the Green scenario the renewable energy takes up 73% in 2030 and 100% in 2030 in the Super Green scenario.

Figure 5 shows the rate of change in renewable energy use over 5-year periods starting from 2005. This explains why the first figure is for year 2010. The Figure shows that even the business as usual scenario will demand a steady increase of renewable energy of just above 1%/year. This is due to the increase in energy consumption. It is therefore necessary to increase the use of renewable energy simply to maintain the current 55% renewable energy share. It may however also be met with increased end-use efficiency.

By way of contrast the Super Green scenario shows that to achieve a 100% renewable energy situation, the use of renewable energy has to increase by 2% to 4% per year, reaching a peak of 4% per year in 2020. In the Super Green scenario, the end-use efficiency improves, at the same time, by 50% by 2030.

The assumption of introducing new technologies in these scenarios is that technology of today is implemented. The curve in Figure 5 will have a very different shape if it constitutes a number of S-curves starting in different years. In general this will be a flatter curve, which may not eventually have to decrease. This will be further modeled in the next part to the study.

Figure 4: Percentage of renewable energy for the three scenarios, starting with the present percentage of 55% (domestic sector only).

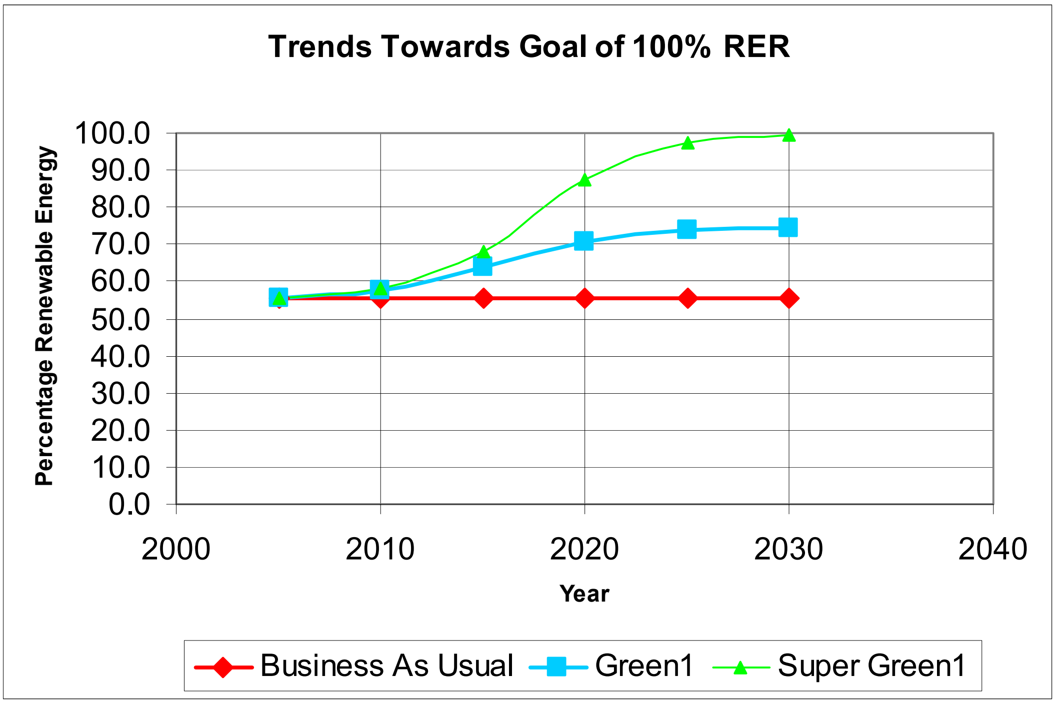
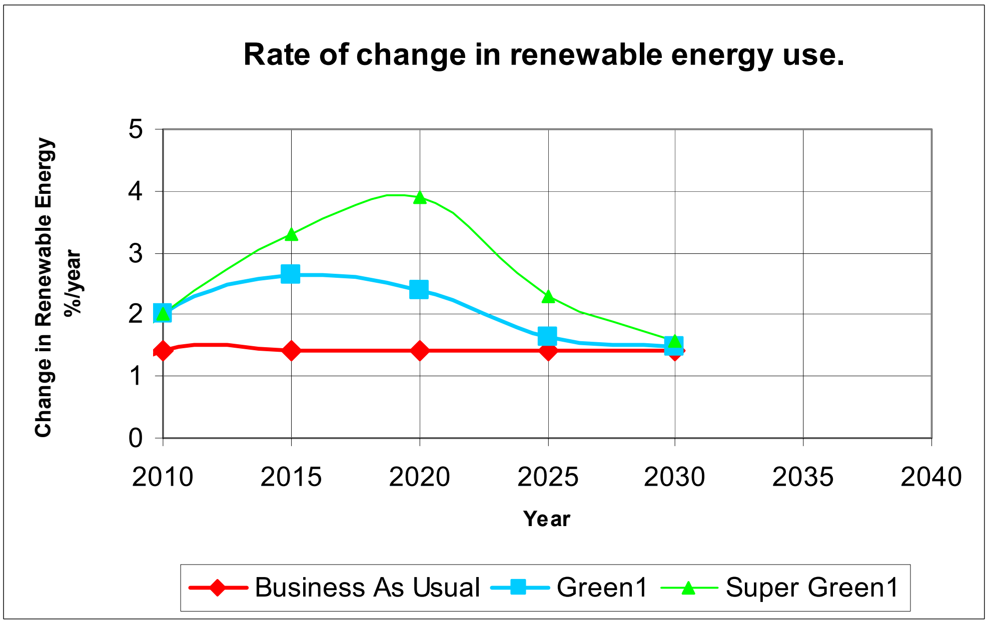


Figure 5: Rate of change in renewable energy use from 2005 to 2030 for the three scenarios.



Discussion

Sustainable energy planning is a complex mixture of using efficient technologies, using less energy, using it in the right form and using renewable energy resources. Reducing the demand makes it easier to achieve a 100% renewable energy Rotorua. But how much will the energy demand increase in the future? The possibility of new industries being started and new more efficient technologies being introduced, makes it difficult to estimate future total consumption with confidence. Estimates also depend on assumptions regarding population and activity growth. In the present study various assumption about the growth in energy consumption is taken.

Whilst improvements in efficiency of use should result in reduction in total consumption, this is not necessarily the case as some of the increased efficiency may be taken as extra benefits rather than reduction of consumption. This has been shown to be the case with home heating (Isaacs *ibid,* 2002). Nevertheless reduction in energy consumption, due to efficiency improvements in some areas, can be allowed for in the model. For some this discussion is known as the discussion of whether energy consumption and economic growth can be decoupled. Where a decoupling has occurred as in Denmark (Nielsen, P, 2002), the reason may be much more complex than referring to a more energy efficient use of technologies. When energy consumption is related to economic growth, structural changes in, for instance, the industrial sector also play a vital role. For instance, relative growth of the service sector compared to the industrial sector makes a difference to the relationship between economic growth and growth in energy consumption.

In the present study, the cost efficiency of the various choices has not been applied. In the next step of the study a technology catalogue will be completed with an attempt to find the most economic choice first. The technologies of choice are both supply technologies and end-use technologies. The challenge is to find the most economic way of achieving a 100% renewable energy Rotorua.

Conclusions

A framework has been established for progressing the concept of 100% Renewable Energy Rotorua on the basis of three scenarios: Business as Usual, Green and Super Green. The framework comprises a model for incorporating changes to the allocation of energy sources to energy end uses over time. The model accounts for such factors as population growth, increased use of appliances, introduction of more efficient appliances and progressive changes from non-renewable resources to renewable resources. Some of these changes over time are assumed to follow the logistic S-curve whose parameters may be selected on the basis of assumptions about the degree of change, the rate of change and the timing of the changes within the period of the study chosen. Other change assumptions, such as for the rate of population growth, are based on predicted percentage increases over time.

At this stage the model only covers the residential sector. During the next year of the study the whole of the Rotorua economy will be covered.

The results shows that the business as usual scenario will have to achieve a steady 1.2% increase in the use of renewable energy to maintain the present share of 55% of renewable energy use in the domestic sector. This is not surprising assuming a 1% increase in energy consumption per year over the full period. But it shows that even to maintain the present role renewable energy plays in the energy sector significant commitment is required. And furthermore, if energy consumption increases more than 1% the changeover to new technologies will simply have to be much stronger just to maintain status quo. If an increase in the use of renewable energy is be achieved, an even stronger approach has to be taken. In the Green and Super green scenarios, the rates of change towards renewable energy sources reach maximum values of 2½% and 4% respectively. This still assumes only a 1% increase in energy consumption per year over the period.

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